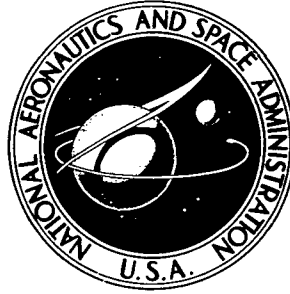


**NASA TECHNICAL
MEMORANDUM**



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**AERODYNAMIC CHARACTERISTICS OF TWO
SINGLE-STAGE-TO-ORBIT VEHICLES
AT MACH 20.3**

Peter T. Bernot

*Langley Research Center
Hampton, Va. 23665*

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16. Abstract The hypersonic stability, control, and performance characteristics of two Langley-designed configurations have been determined. Each configuration (0.0025 scale) had a 50° swept delta wing, a vertical tail, and a body flap. One model represented a control-configured vehicle with a reduced level of longitudinal static stability; the other model was designed for a more conventional level of stability. Data were obtained over an angle-of-attack range of 0° to 50° and included effects of component buildup. In addition, the effects of the vertical tail on the lateral-directional characteristics were obtained over angles of attack ranging from 0° to 18°. This investigation was conducted in the 22-inch aerodynamics leg of the Langley hypersonic helium tunnel facility.					
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AERODYNAMIC CHARACTERISTICS OF TWO SINGLE-STAGE-TO-ORBIT VEHICLES AT MACH 20.3

Peter T. Bernot
Langley Research Center

SUMMARY

The aerodynamic characteristics of two single-stage-to-orbit concepts have been obtained experimentally at Mach 20.3 in the 22-inch aerodynamics leg of the Langley hypersonic helium tunnel facility. Both configurations employed 50° swept delta wings, vertical tails, and body flaps and were tested over an angle-of-attack range of 0° to 50° . Model 1, designed as a control-configured vehicle, had a more slender body than model 2 and indicated good longitudinal stability characteristics. With elevon and body-flap deflections, model 1 had a trim capability at angles of attack between 30° and 50° . Values of trimmed lift-drag ratio ranged from 1.45 to 0.80 for typical reentry attitudes of 30° to 50° . Model 2, designed for a conventional level of longitudinal stability, had a wing planform area 50 percent larger than that of model 1. Model 2 also indicated some trim capability at angles of attack from about 30° to 50° .

The lateral-directional characteristics obtained over an angle-of-attack range of 0° to 18° showed directional instability for both models despite the favorable effects of the vertical tails. This instability was expected because of the rearward locations of the centers of gravity (at 69 percent of reference body length for model 1 and 70 percent of reference body length for model 2). Positive dihedral effect occurred at angles of attack greater than 8° for model 1 and from 0° to 18° for model 2 which had the larger wing.

INTRODUCTION

Studies are now underway by the National Aeronautics and Space Administration (NASA) and the aerospace industry to identify the technology requirements for an advanced, fully reusable space transportation system that could be operational before the turn of the century. Estimates of future improvements in structures, thermal protection materials, and rocket propulsion systems have been incorporated into the design of several single-stage-to-orbit vehicles (ref. 1). Current studies are focused on delta-wing configurations with single vertical tails; the size of these configurations allow them to transport a baseline payload up to 29 483 kg (65 000 lb) to near-Earth orbit. Costing techniques applied to these advance systems have indicated significant reductions in cost per flight by factors of 6 to 8 when compared with the current space shuttle concept. (See refs. 2 and 3.)

The Langley Research Center has been investigating new technological developments that can also favorably affect the cost and performance of these future systems. One area that has been studied is the relaxation of conventional

vehicle static longitudinal-stability requirements. Using existing vehicle design analysis techniques (ref. 4), two single-stage-to-orbit vehicles have been designed to meet the same mission requirements. One vehicle was designed for a conventional level of static longitudinal stability, and the other was a control-configured vehicle that would have reduced stability levels.

Both Langley-designed configurations incorporated delta wings with a 50° sweep, a vertical tail, and a body flap. The control-configured vehicle has a relatively slender fuselage with a full-scale reference length of 66.79 m (219.12 ft) and a delta wing with a total planform area of 557.42 m² (6000 ft²). The conventionally designed vehicle is shorter, with a fuselage length of 57.64 m (189.12 ft), but has a larger wing whose planform area is 50 percent greater. This overall study primarily determines experimental aerodynamic characteristics from wind-tunnel tests over the Mach number range and, thereby, provides inputs for evaluation of the configurations.

This paper presents the stability, control, and performance characteristics of both configurations at hypersonic speeds. Force and moment data were obtained on 0.0025-scale models of both configurations at a Mach number of 20.3 over an angle-of-attack range of 0° to 50°. Also included in this report are the effects of component buildup and the effects of the vertical tail on the lateral-directional characteristics at angles of attack of 0° to 18°. This investigation was conducted in the 22-inch aerodynamics leg of the Langley hypersonic helium tunnel facility.

SYMBOLS

The longitudinal characteristics are based on both the body- and stability-axis systems. The lateral-directional characteristics are based on the body-axis system only. Values are given in both SI and U.S. Customary Units. Measurements were made in U.S. Customary Units.

b	wing span, m (ft)
C _A	axial-force coefficient, $\frac{\text{Axial force}}{qS}$
C _D	drag coefficient, $\frac{\text{Drag}}{qS}$
C _L	lift coefficient, $\frac{\text{Lift}}{qS}$
C _l	rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb}$
C _{lβ}	rate of change of rolling-moment coefficient with sideslip angle, $\frac{\Delta C_l}{\Delta \beta}$, per deg

C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$
C_N	normal-force coefficient, $\frac{\text{Normal force}}{qS}$
C_n	yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$
$C_{n\beta}$	rate of change of yawing-moment coefficient with sideslip angle, $\frac{\Delta C_n}{\Delta \beta}$, per deg
C_Y	side-force coefficient, $\frac{\text{Side force}}{qS}$
$C_{Y\beta}$	rate of change of side-force coefficient with sideslip angle, $\frac{\Delta C_Y}{\Delta \beta}$, per deg
$\bar{c}$	wing mean aerodynamic chord, m (ft)
L/D	lift-drag ratio, $\frac{C_L}{C_D}$
l	fuselage reference length, m (ft)
M	Mach number
q	dynamic pressure, Pa (psia)
R_l	Reynolds number based on fuselage length
S	total wing planform area, m^2 (ft^2)
α	angle of attack, deg
β	sideslip angle, deg
δ_{BF}	body-flap deflection angle, positive with trailing edge down, deg
δ_e	elevon-deflection angle, positive with trailing edge down, deg

Model component designations:

B	body alone
F	body flap
V	vertical tail
W	wing

DESCRIPTION OF MODELS

The two test models were 0.0025-scale versions of single-stage-to-orbit vehicles that were designed and fabricated at the Langley Research Center. Model 1, which represented the control-configured vehicle (fig. 1(a)), was characterized by a slender fuselage with a fineness ratio of 4.955 and a delta wing with a leading-edge sweep angle of 50° . The more conventionally designed model 2 (fig. 1(b)) had a shorter fuselage (fineness ratio of 4.089) and a 50° swept wing whose planform area was 50 percent greater than that of model 1. Both wings had an aspect ratio of 2.48 and 7° of dihedral. Geometric characteristics of the full-scale configurations are presented in table I. The model fuselages were made from wood, and the wings, tails, and body flap were machined from metal. Photographs of the test models are presented in figure 2. Because of the thinness of the model wing, a separate wing was fabricated for each elevon deflection angle. Measured values of elevon and body-flap deflection angles are used in this paper. In addition, transverse curvature existed on the bottom surface of the fuselage just ahead of the body flap on model 2 and probably produced partial shielding on the simplified planar flap. Thus, the data for this model could be influenced by this shielding of the flap.

The centers of gravity of models 1 and 2 were located at 69 and 70 percent of the reference body lengths, respectively. The actual body lengths were somewhat shorter because of nose blunting as shown in figure 1.

APPARATUS AND TESTS

Wind Tunnel

This investigation was conducted in the 22-inch aerodynamics leg of the Langley hypersonic helium tunnel facility which is an intermittent, closed-cycle, blowdown facility. The tunnel facility has a contoured axisymmetric nozzle with circular cross sections and a nominal test-section Mach number of 20. Calibration surveys (ref. 5) indicate a range of average Mach numbers from 17.6 to 22.2 at stagnation pressures of 1.38 MPa (200 psia) to 20.68 MPa (3000 psia), respectively. The tunnel facility is generally operated at stagnation temperatures near ambient; however, temperature may be varied up to 533.3 K (500° F) by use of an electrical resistance heater. The average duration of a test run is about 30 seconds; the helium is then collected, purified, and stored in high-pressure tanks for subsequent tests. Additional information can be found in reference 5.

Tests

All tests were conducted at a stagnation pressure of 6.89 MPa (1000 psia) and at a temperature of about 288.9 K (60° F). The free-stream Mach number was 20.3 at a unit Reynolds number of 22.7×10^6 per meter. The free-stream flow properties were corrected for real-gas effects by the methods of reference 6, and the Reynolds numbers were calculated using the correction factors presented in reference 7 to account for low temperature effects on helium viscosity.

Force and moment data were obtained by two sting-supported, six-component strain-gage balances. For the low angle-of-attack range of 0° to 18°, a straight sting was used; a 30°-bent sting was required to encompass the high angle-of-attack range of 20° to 50°. Data were obtained at predetermined angles of attack by using a prism mounted flush on the model fuselage to reflect light from a point (adjacent to the test-section window) onto electric eyes aligned at calibrated intervals. Additional features of this system can also be found in reference 5. Lateral-directional data were obtained only for the low-angle-of-attack range. These data were obtained by using an offset sting with a fixed sideslip angle of approximately 4.8°.

The estimated uncertainties in the measured data were based on ± 0.5 percent of the balance design loads and are shown in the following table:

Coefficients	Estimated uncertainties for -			
	Model 1		Model 2	
	Low α	High α	Low α	High α
C_N	± 0.0070	± 0.0210	± 0.0050	± 0.0140
C_A	.0023	.0030	.0016	.0020
C_m	.0053	.0100	.0029	.0055
C_l	.0006	.0019	.0003	.0010
C_n	.0006	.0019	.0003	.0010
C_y	.0020	.0070	.0016	.0050

The accuracy of the angles of attack and sideslip was estimated to be $\pm 0.1^\circ$; the free-stream Mach number is estimated to be accurate to ± 0.2 . Base pressures were measured at one location for all tests, and the axial-force coefficients were adjusted to correspond to a base pressure equal to the free-stream static pressure.

RESULTS AND DISCUSSION

Component Buildup

The effects of component buildup on the longitudinal and lateral-directional characteristics of models 1 and 2 for an angle-of-attack range of 0° to 18° are presented in figures 3 and 4, respectively. For model 1, the

body-alone results indicated a maximum L/D of 2.30; adding the wing and vertical tail caused a reduction to approximately 2.1. The body of model 2, which was shorter than model 1, had a maximum L/D of 1.90. However, the addition of the wing and vertical tail resulted in a very small reduction in the maximum L/D. The addition of the larger wing for model 2 also resulted in larger drag increments in comparison with model 1 as the angle of attack increased.

The effects of the vertical tail on the lateral-directional characteristics for models 1 and 2 are presented in figures 3(d) and 4(d), respectively. As expected, the addition of the tail resulted in some improvement in $C_{l\beta}$ and

C_{ng} at the lower angles of attack for both models. The tail became ineffective

near an angle of attack of 12° for model 1 and at about a 15° angle of attack for model 2. The body-wing-tail versions of both models were directionally unstable as expected because of the rearward center-of-gravity locations. Positive dihedral effect ($-C_{l\beta}$) was obtained for model 1 at angles of attack greater

than 8° and over the entire angle-of-attack range for model 2 due to its larger wing. Although these versions did not incorporate a body flap, the results just discussed should be representative of the complete configurations.

The longitudinal characteristics of the body-alone and the body-wing-tail versions of both models over an angle-of-attack range of 0° to 50° are presented in figures 5 and 6. Examination of the plotted coefficients which were obtained by the use of straight and bent stings indicates good continuity between the two sets of data for each model. Maximum values of C_L for both the body-alone and body-wing-tail for model 1 occur near an angle of attack of 50° ; for model 2, the maximum C_L values appear to occur at angles of attack slightly greater than 50° . As mentioned previously, the addition of the wing to the body of model 2 produced larger drag increments than those of model 1 as angle of attack increased to 50° .

Complete Configurations

The effects of elevon and body-flap deflections on the longitudinal characteristics of the complete configurations (models 1 and 2) are presented in figures 7 and 8, respectively. With the center of gravity located at 69 percent of body length, model 1 has essentially neutral longitudinal stability near an angle of attack of 24° for combined positive deflections of the elevons and body flap. For separate deflections of either the elevons or the body flap, stable trim conditions are possible for angles of attack from 46° to angles exceeding 50° . For a range of reentry angles of attack of 30° to 50° , model 1 yielded trim L/D values of 1.45 to 0.8, respectively. Maximum values of C_L occur generally at angles of attack slightly greater than 50° . Therefore, the hypersonic stability and performance characteristics of model 1 make it a viable configuration.

In figure 8, the longitudinal characteristics of model 2 are presented for a center-of-gravity location at 70 percent of body length. The data as shown

are restricted to elevon deflections only. As mentioned previously, some shielding of the flow on the undeflected body flap may have occurred. Since trim conditions were bracketed by the elevon deflections tested, a linear interpolation of the C_m data plotted against the α data of figure 8(b) was made. The assumed linearity of C_m plotted against elevon deflection yielded neutral stability at angles of attack near 28° and 50° for elevon deflections of 10° and 6° , respectively. Positive deflection of the body flap would probably improve the trim capability of model 2 in a manner similar to that shown for model 1. At reentry attitudes of 30° to 50° , the L/D values are about the same as those of model 1. Despite the lack of body-flap data, the aerodynamic characteristics for model 2 were generally favorable at hypersonic speeds.

CONCLUDING REMARKS

The aerodynamic characteristics of two single-stage-to-orbit concepts have been obtained at Mach 20.3 in the 22-inch aerodynamic leg of the Langley hypersonic helium tunnel facility. Both configurations had 50° swept wings, vertical tails, and body flaps and were tested over an angle-of-attack range of 0° to 50° . Model 1 (control-configured vehicle), which was more slender than model 2, indicated good longitudinal-stability characteristics with a trim capability over an angle-of-attack range from 30° to at least 50° using elevon and body-flap deflections. Values of trimmed lift-drag ratio ranged from 1.45 to 0.8 for typical reentry attitudes of 30° to 50° . Model 2 (conventional design), which had a wing planform area 50 percent larger than model 1, also exhibited some trim capability at angles of attack from about 30° to 50° .

The lateral-directional characteristics of both models at the low angle-of-attack range (0° to 18°) showed directional instability despite the favorable effects of the vertical tails. This instability was expected because of the rearward locations of the centers of gravity. Positive dihedral effect was obtained at angles of attack greater than 8° for model 1 and over the low angle-of-attack range for model 2 which had the larger wing.

Langley Research Center
National Aeronautics and Space Administration
Hampton, VA 23665
June 14, 1977

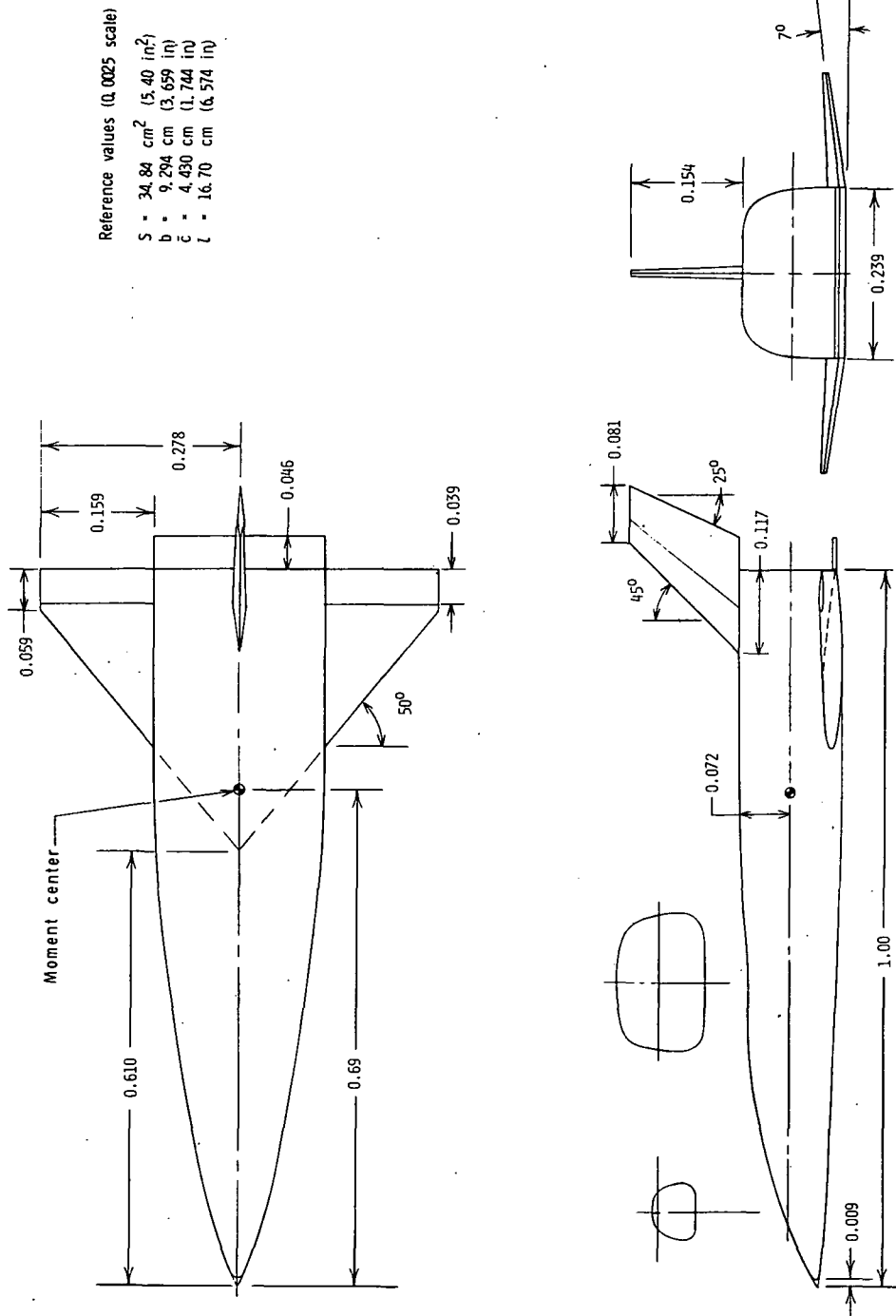
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TABLE I.- FULL-SCALE GEOMETRIC CHARACTERISTICS OF CONFIGURATIONS

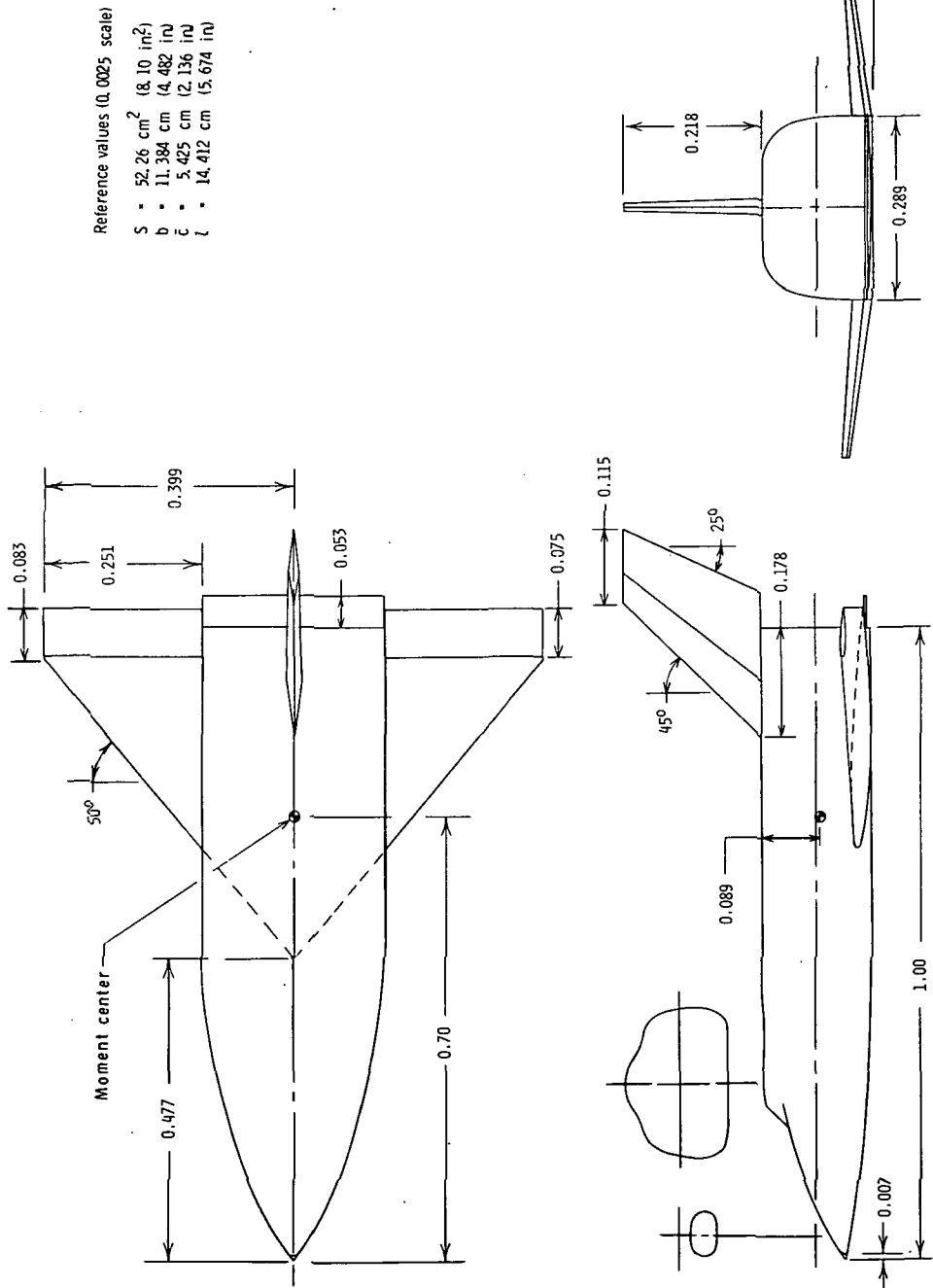
	No. 1	No. 2
Fuselage:		
Length, m (ft)	66.79 (219.12)	57.64 (189.12)
Maximum width, m (ft)	15.93 (52.26)	16.66 (54.66)
Fineness ratio ^a	4.955	4.089
Base area, m ² (ft ²)	142.61 (1535)	156.0 (1679.2)
Planform area, m ² (ft ²)	815.21 (8774.9)	810.37 (8722.7)
Wing:		
Total area, m ² (ft ²)	557.42 (6000)	836.13 (9000)
Span, m (ft)	37.18 (121.98)	45.54 (149.40)
Root chord at center line, m (ft)	26.07 (85.53)	31.93 (104.75)
Tip chord, m (ft)	3.91 (12.84)	4.79 (15.73)
Mean aerodynamic chord, m (ft)	17.72 (58.14)	21.7 (71.20)
Aspect ratio	2.48	2.48
Leading-edge sweep, deg	50	50
Dihedral angle, deg	7	7
Incidence angle, deg	1.5	1.5
Airfoil section at root	NACA 0008-64	NACA 0008-64
Airfoil section at tip	NACA 0012-64	NACA 0012-64
Elevon chord, m (ft)	2.62 (8.61)	4.34 (14.25)
Elevon span per side, m (ft)	10.63 (34.86)	14.44 (47.37)
Elevon total area, m ² (ft ²)	55.74 (600)	125.42 (1350)
Vertical tail:		
Root chord, m (ft)	10.88 (35.71)	13.33 (43.74)
Tip chord, m (ft)	5.41 (17.74)	6.62 (21.73)
Area, m ² (ft ²)	83.61 (900)	125.42 (1350)
Span, m (ft)	10.27 (33.68)	12.57 (41.24)
Leading-edge sweep, deg	45.0	45.0
Trailing-edge sweep, deg	25.0	25.0
Airfoil section	Wedge	Wedge
Body flap:		
Chord, m (ft)	3.05 (10)	3.05 (10)
Span, m (ft)	15.93 (52.26)	16.66 (54.66)
Area, m ² (ft ²)	48.55 (522.58)	50.78 (546.57)

^aValues of fineness ratio are obtained by dividing the fuselage length by the diameter of a circle whose area equals the fuselage base area.



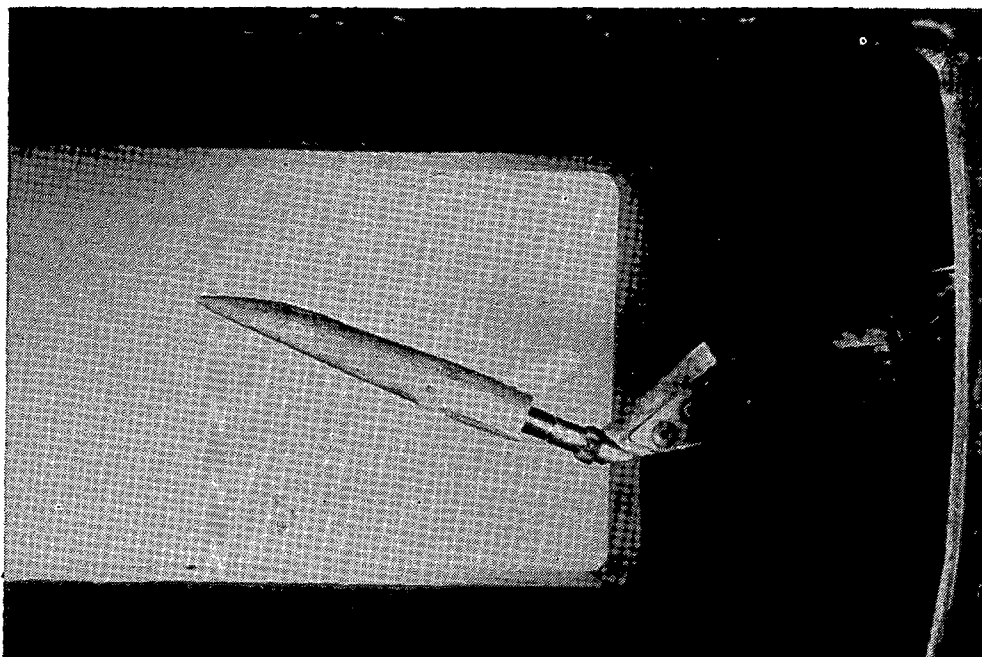
(a) Model 1.

Figure 1.- Model drawings with linear dimensions normalized by reference body length 1.

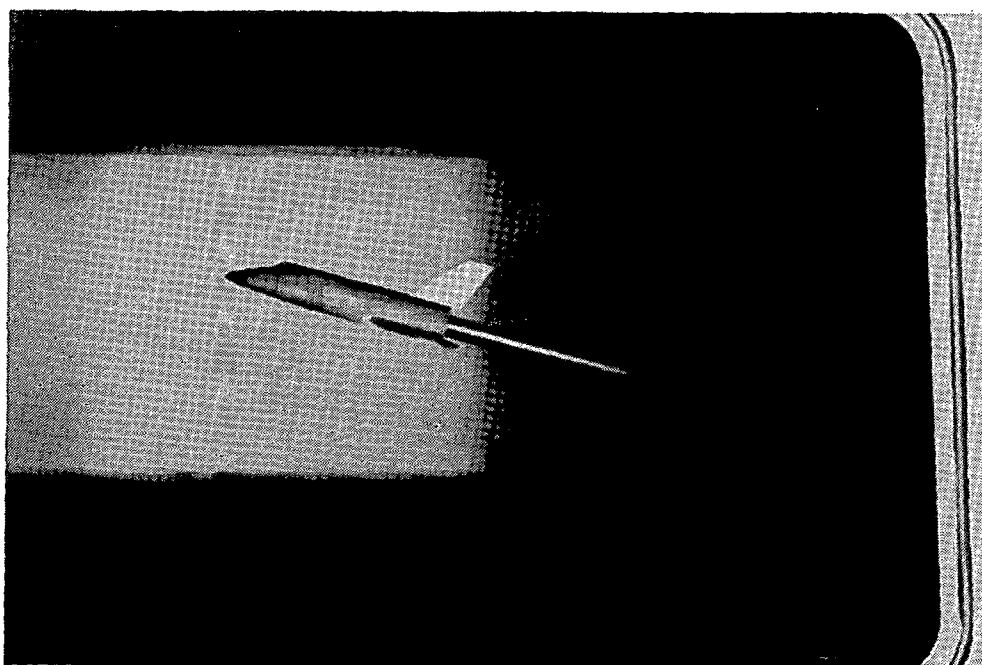


(b) Model 2.

Figure 1.- Concluded.



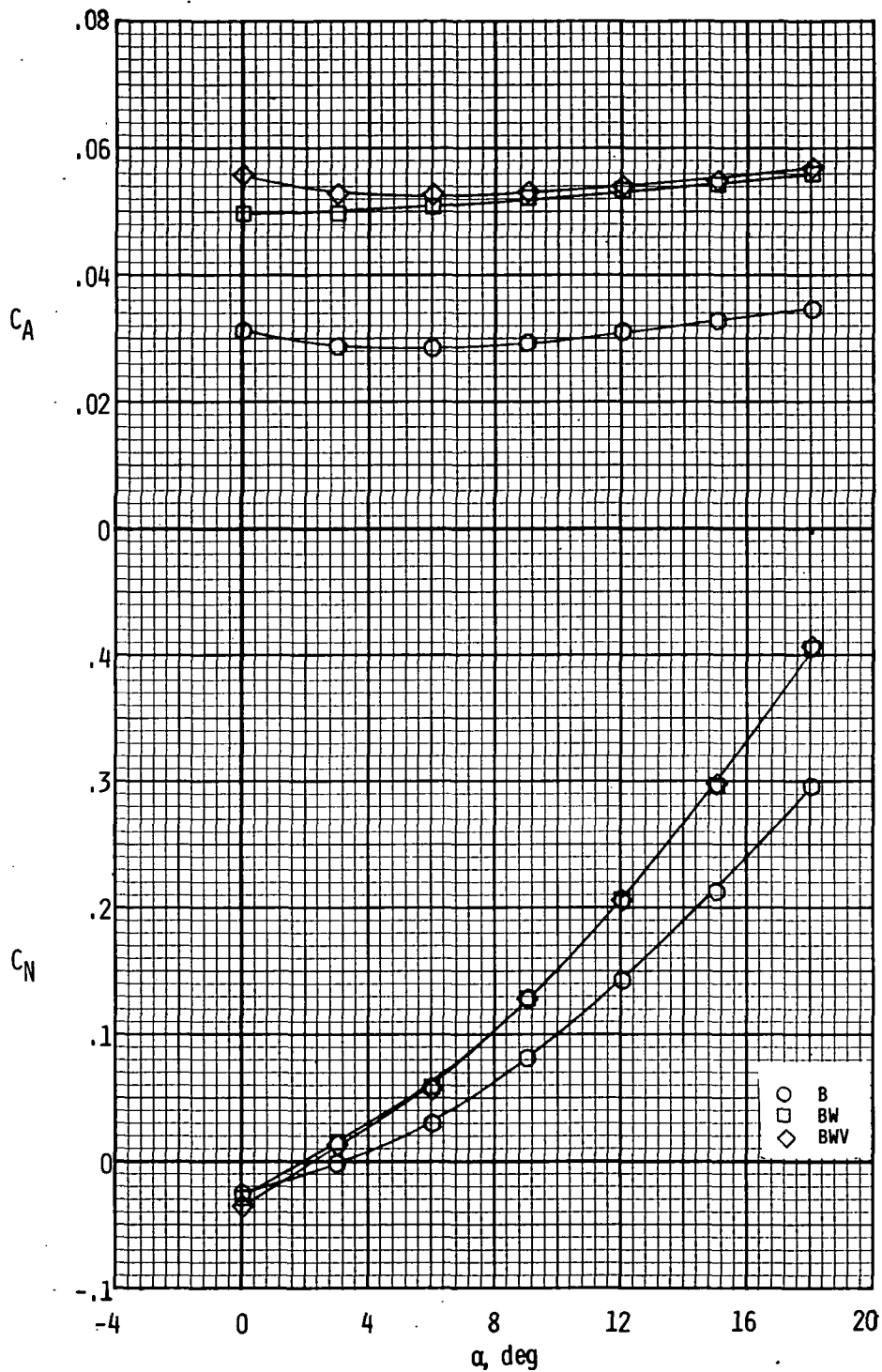
(a) Model 1 mounted on 30° sting.



(b) Model 2 mounted on straight sting.

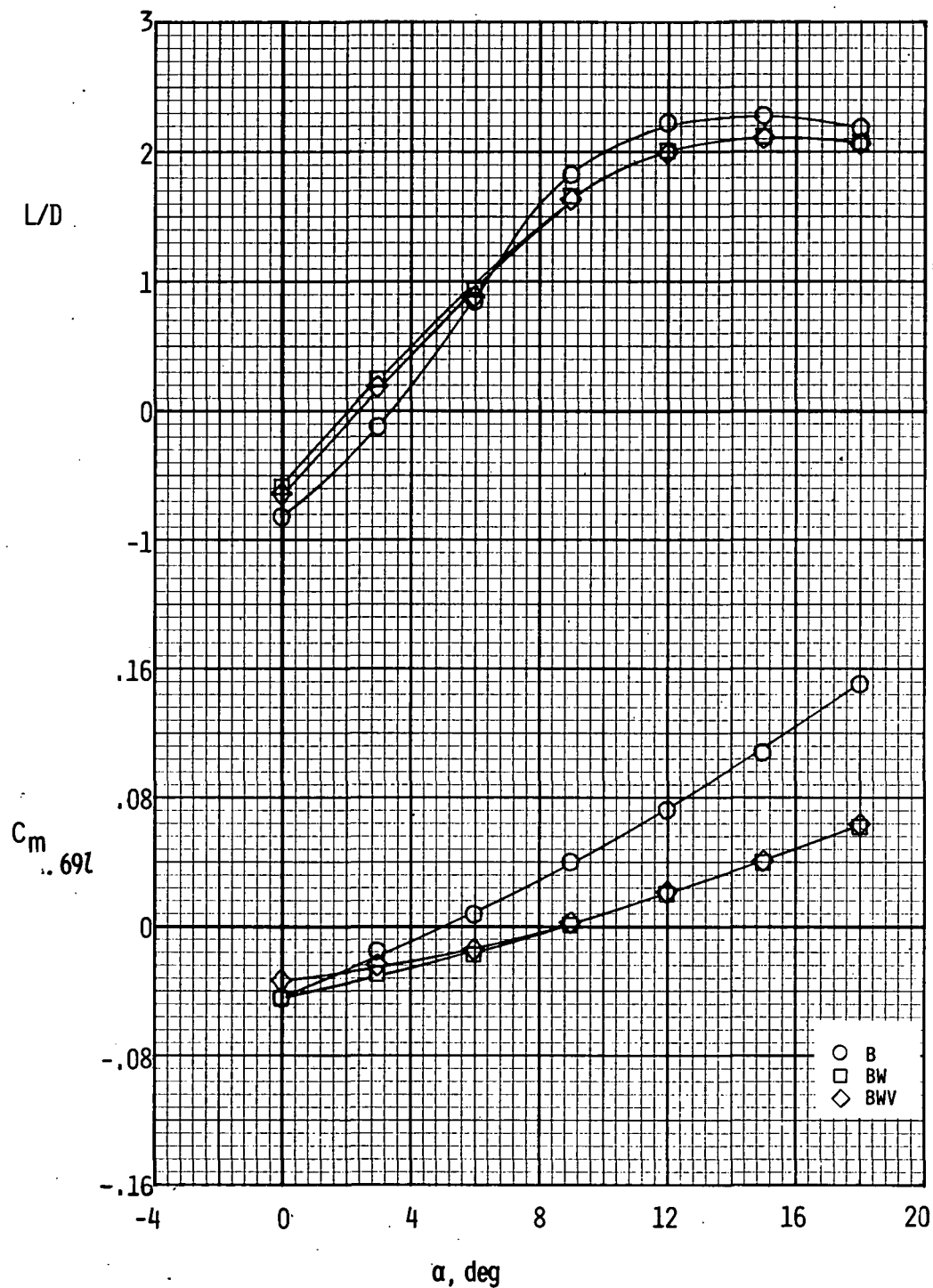
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Figure 2.- Model-sting arrangements in 22-inch aerodynamics leg of the Langley hypersonic helium tunnel facility.



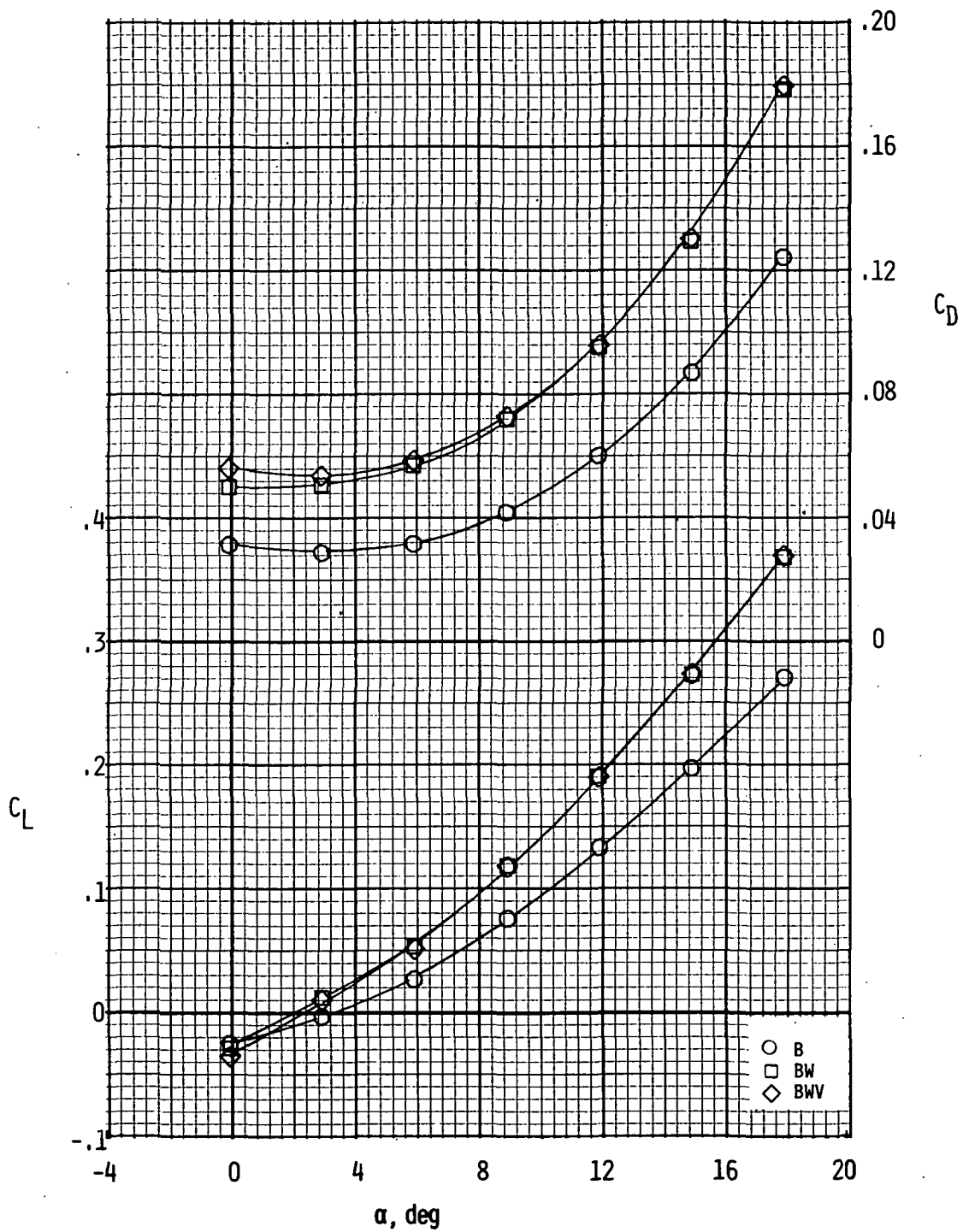
(a) C_A and C_N plotted against α .

Figure 3.- Effect of component buildup on aerodynamic characteristics at low angles of attack. Model 1; $M = 20.3$; $R_1 = 3.79 \times 10^6$.



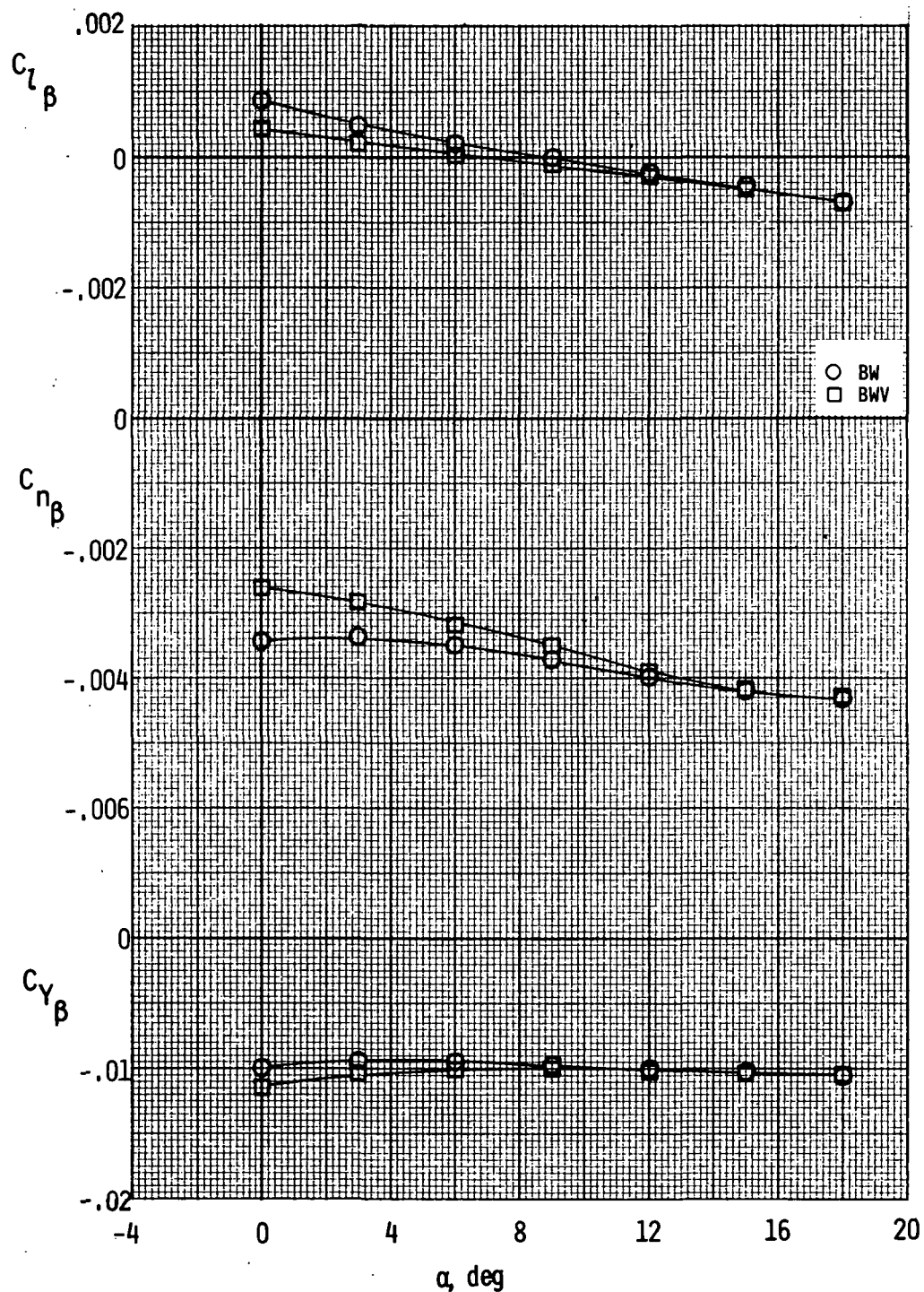
(b) L/D and C_m plotted against α .

Figure 3.- Continued.



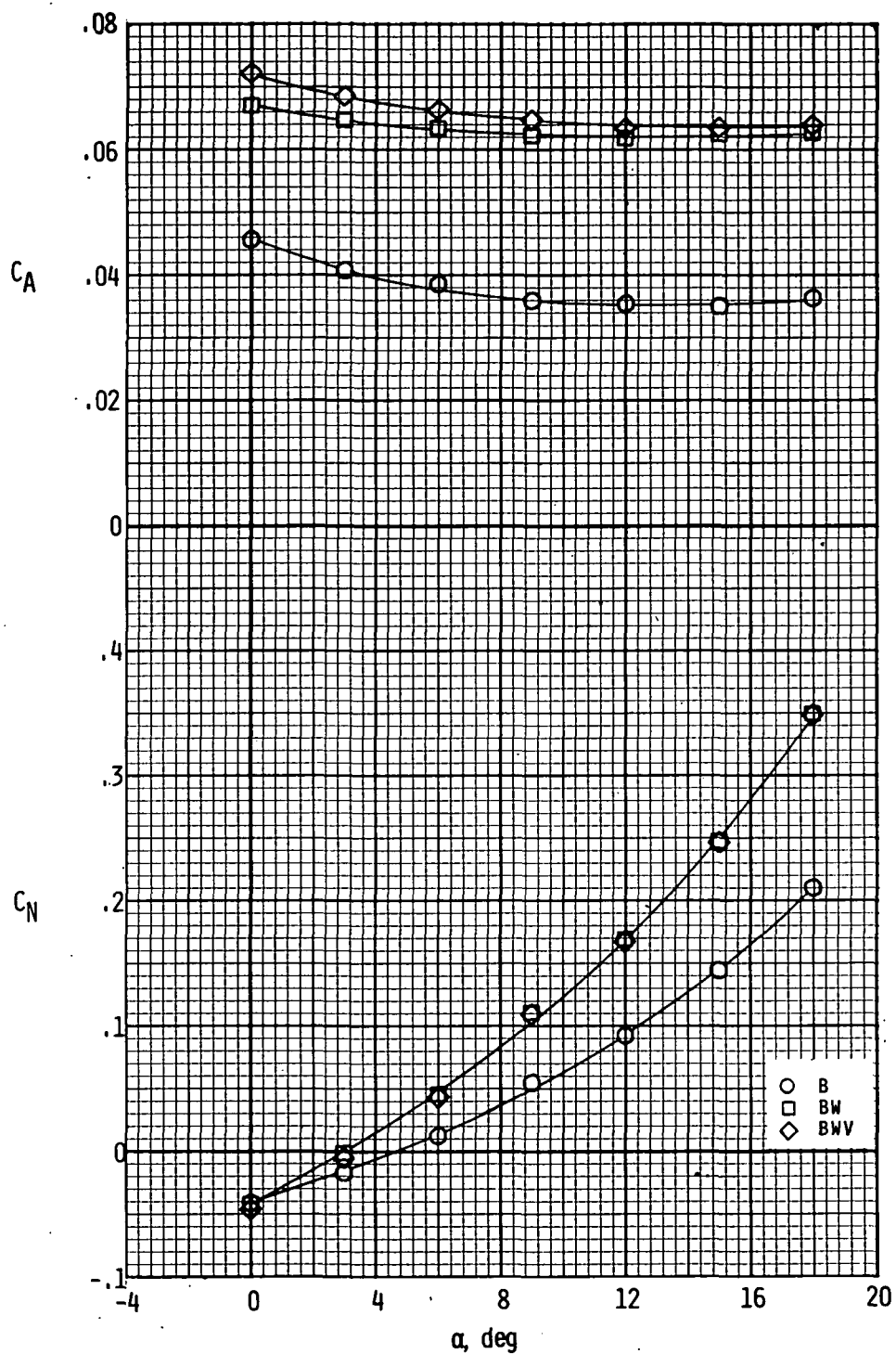
(c) C_D and C_L plotted against α .

Figure 3.- Continued.



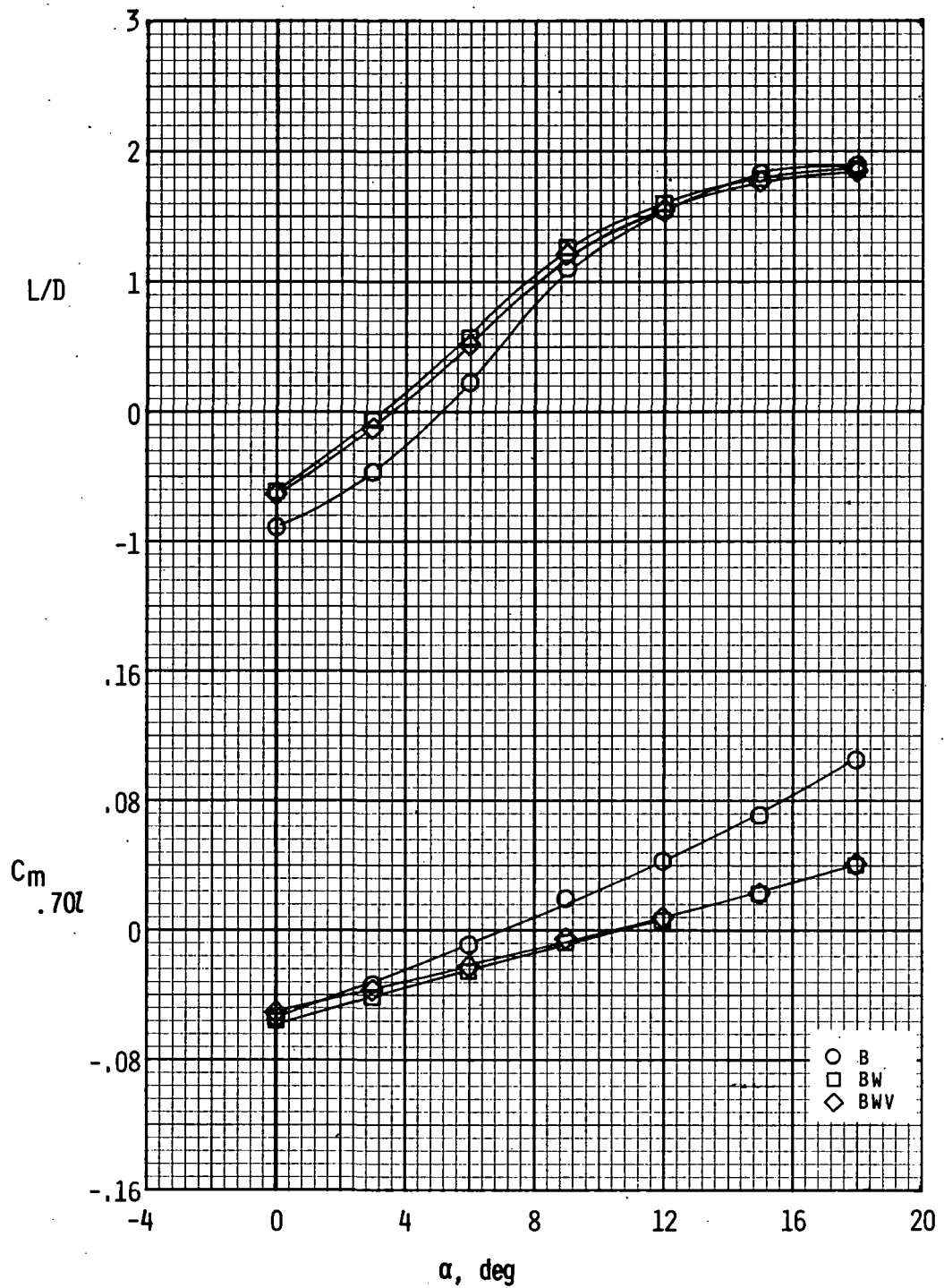
(d) Lateral-directional characteristics.

Figure 3.- Concluded.



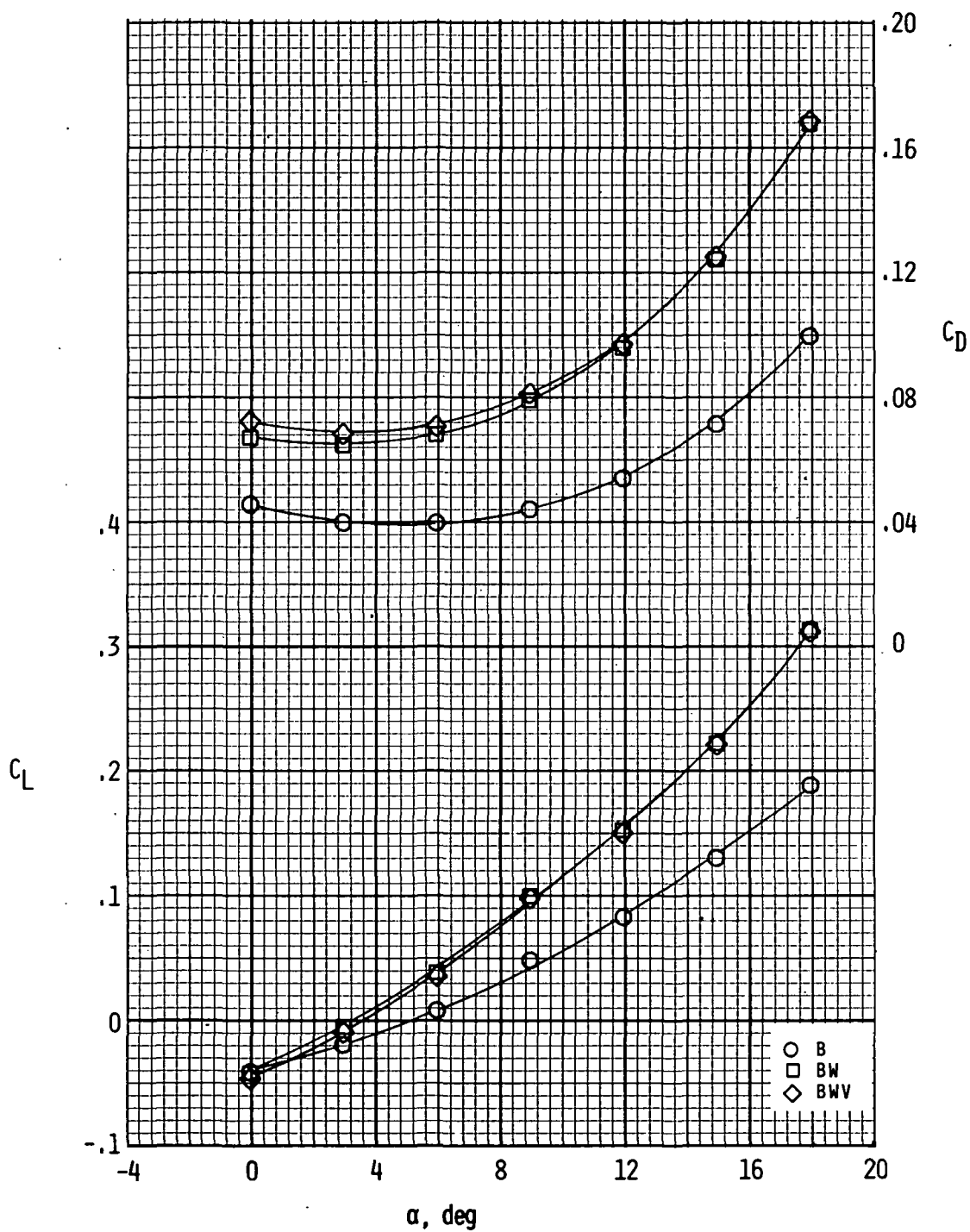
(a) C_A and C_N plotted against α .

Figure 4.- Effect of component buildup on aerodynamic characteristics at low angles of attack. Model 2; $M = 20.3$; $R_1 = 3.27 \times 10^6$.



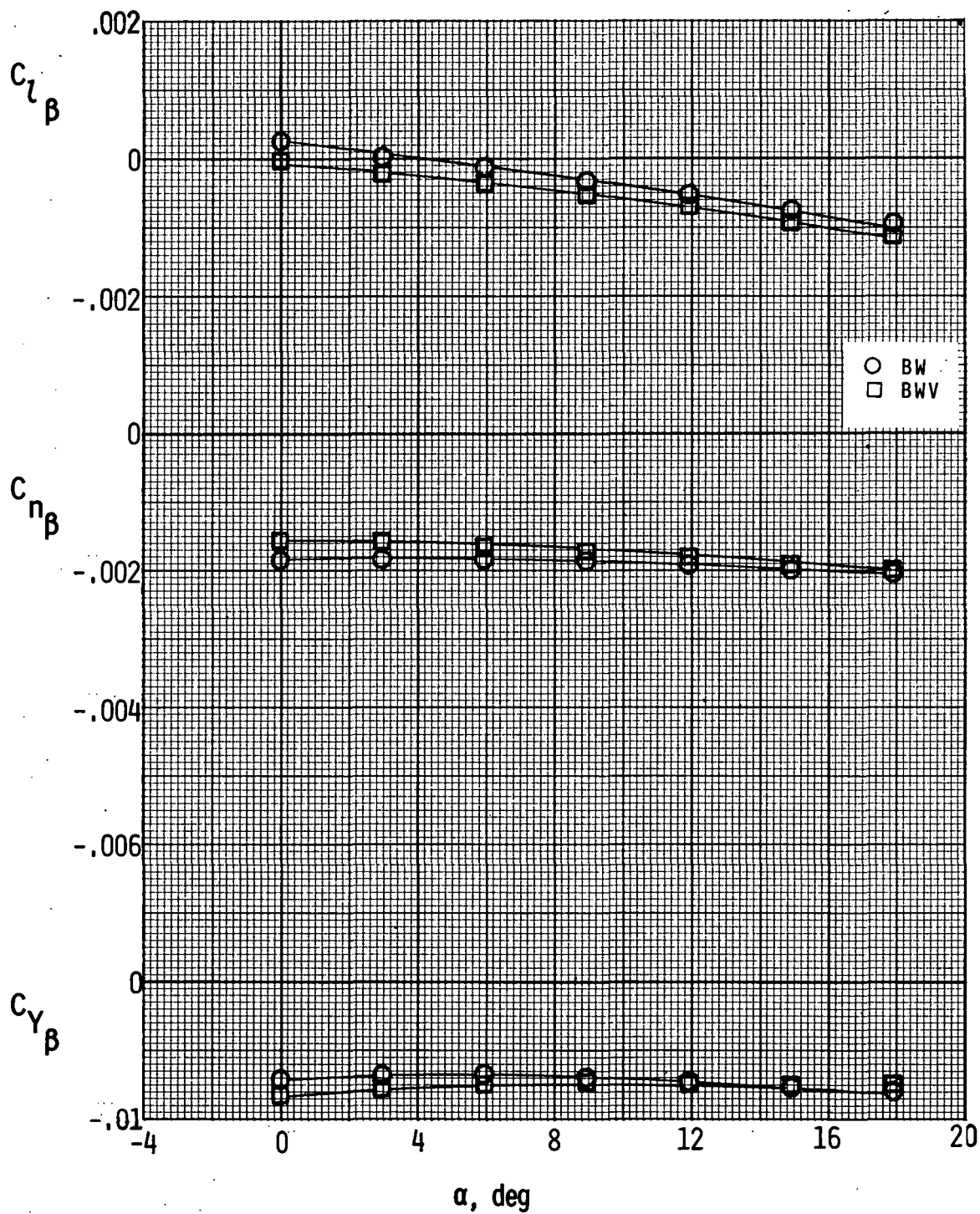
(b) L/D and C_m plotted against α .

Figure 4.- Continued.



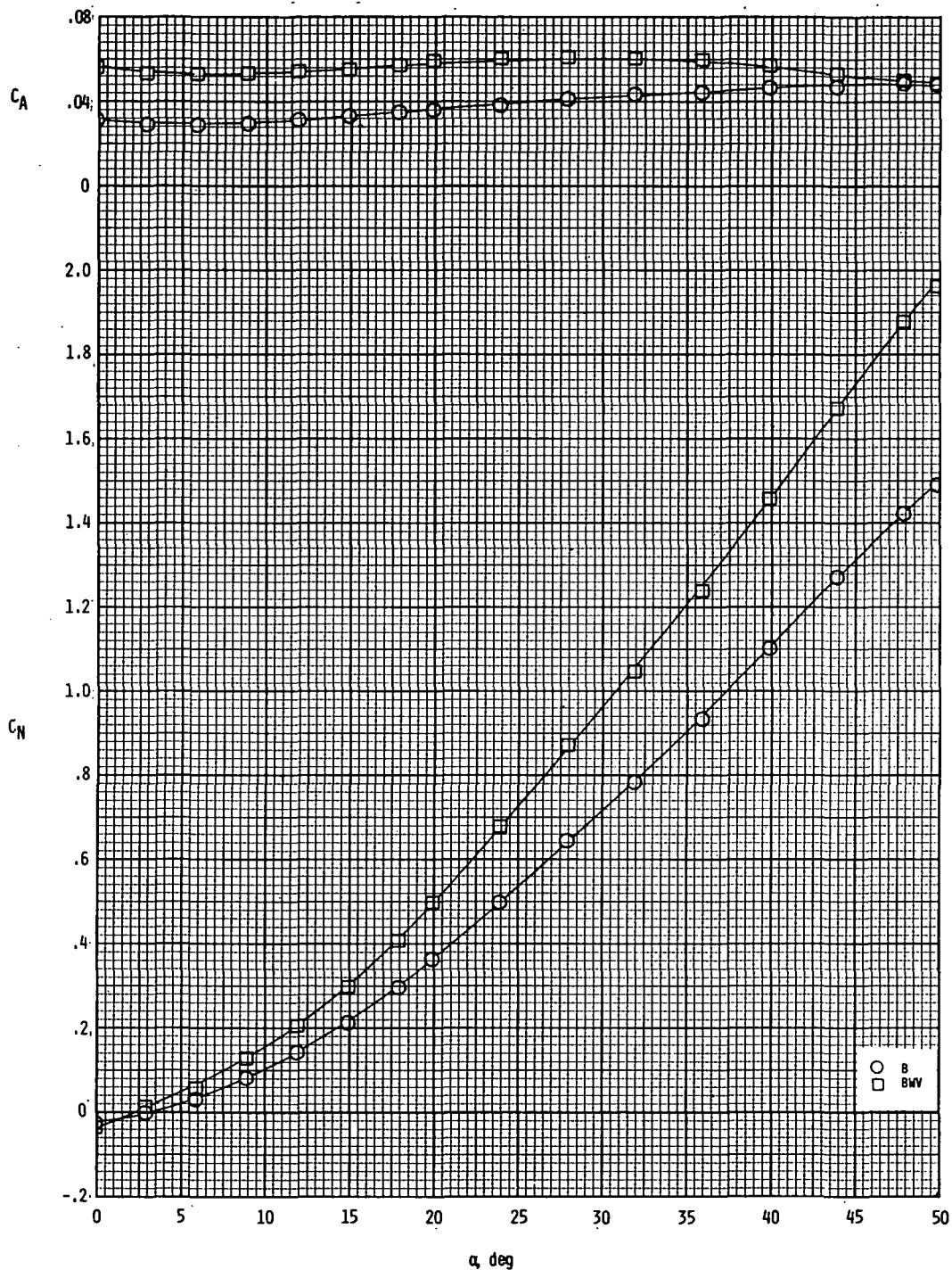
(c) C_D and C_L plotted against α .

Figure 4.- Continued.



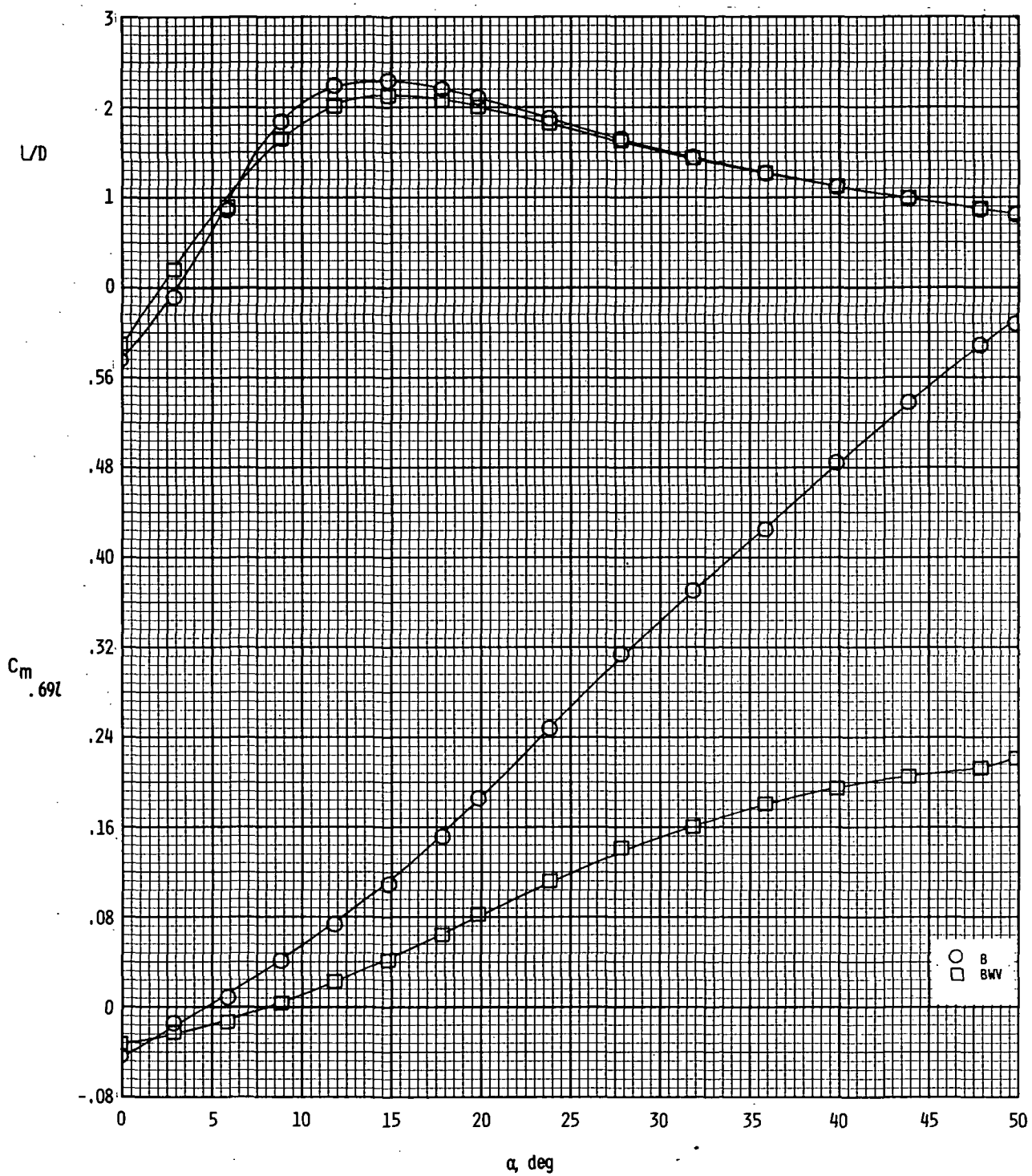
(d) Lateral-directional characteristics.

Figure 4.- Concluded.



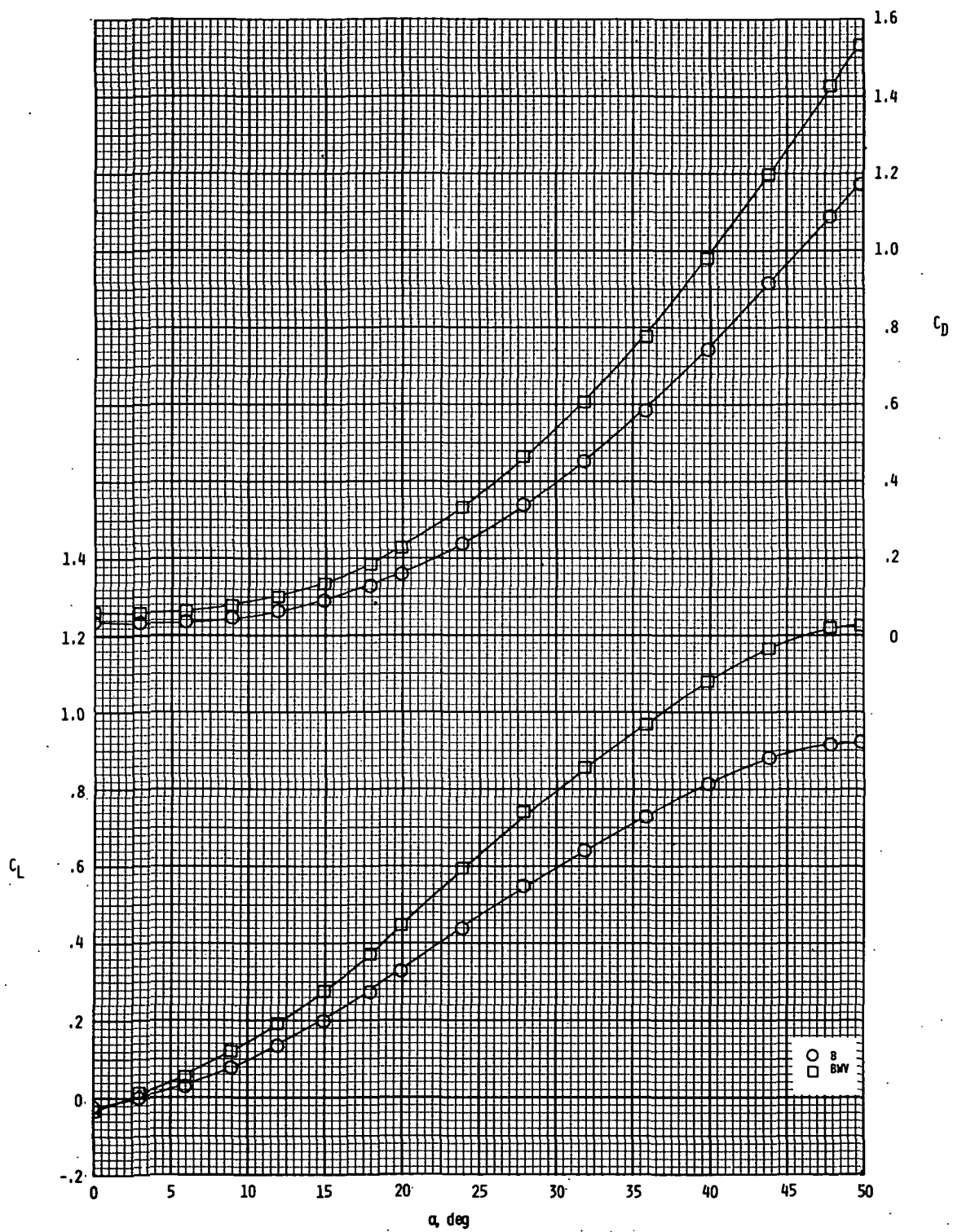
(a) C_A and C_N plotted against α .

Figure 5.- Effect of component buildup on longitudinal characteristics over complete angle-of-attack range. Model 1; $M = 20.3$; $R_1 = 3.79 \times 10^6$.



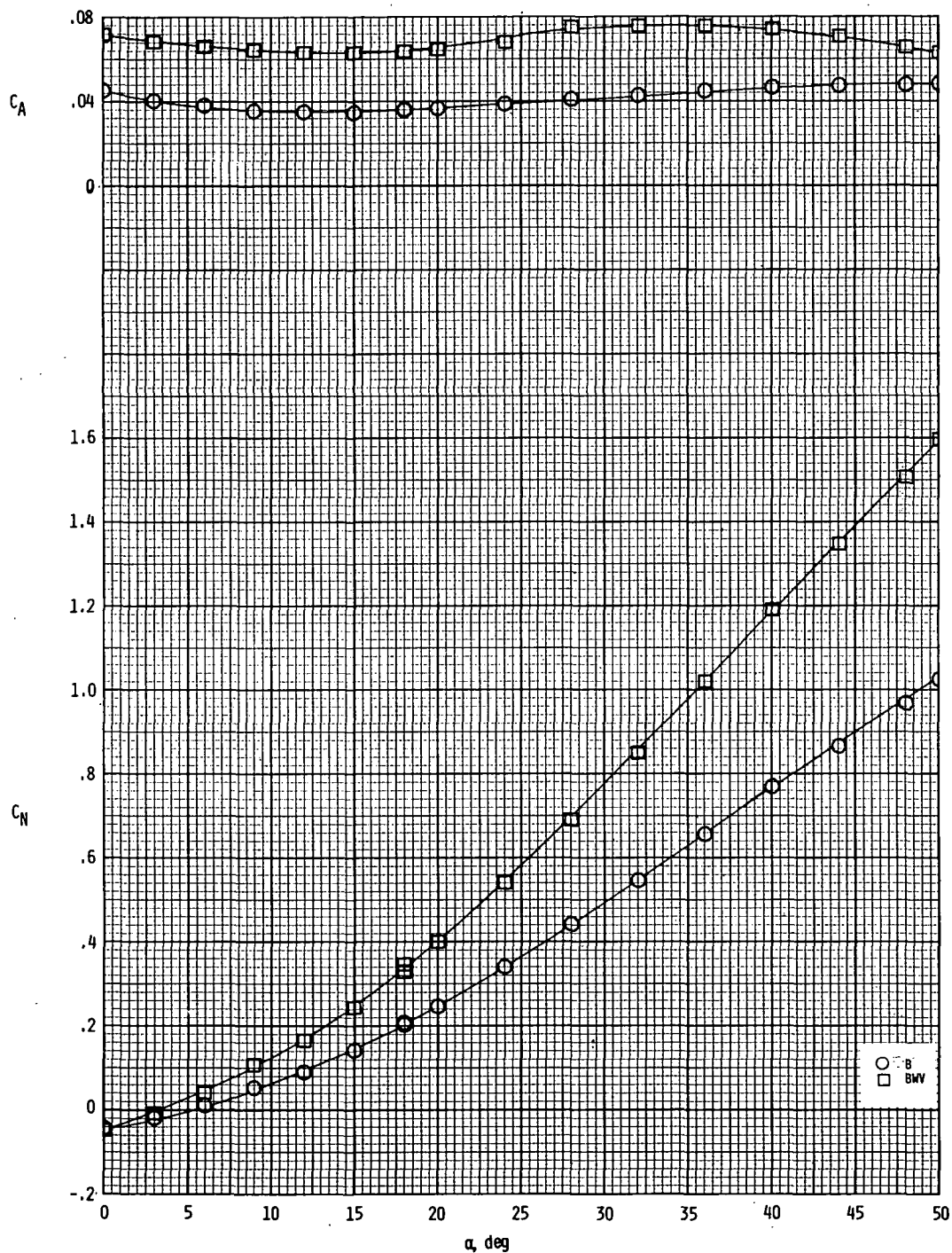
(b) L/D and C_m plotted against α .

Figure 5.- Continued.



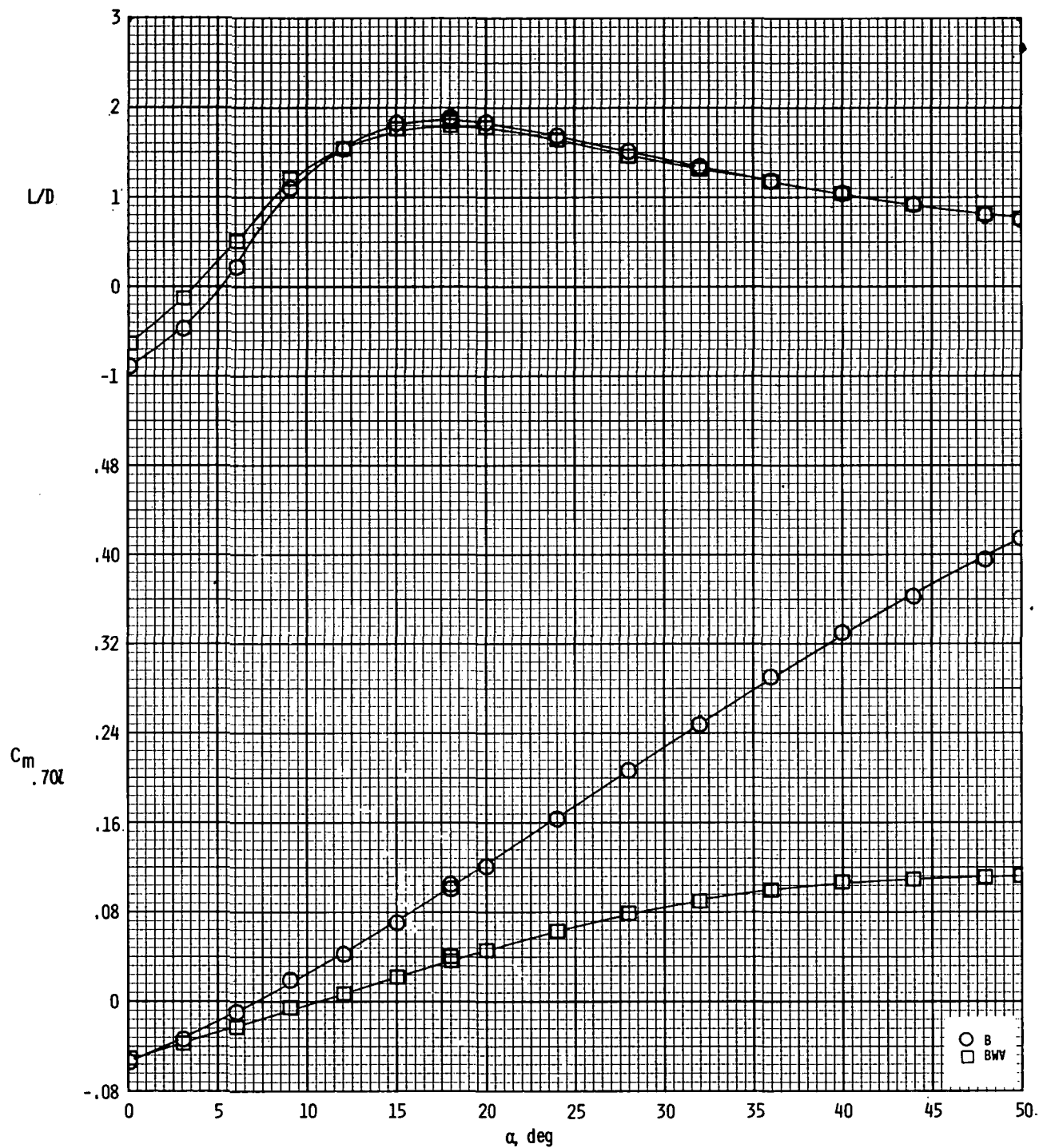
(c) C_D and C_L plotted against α .

Figure 5.- Concluded.



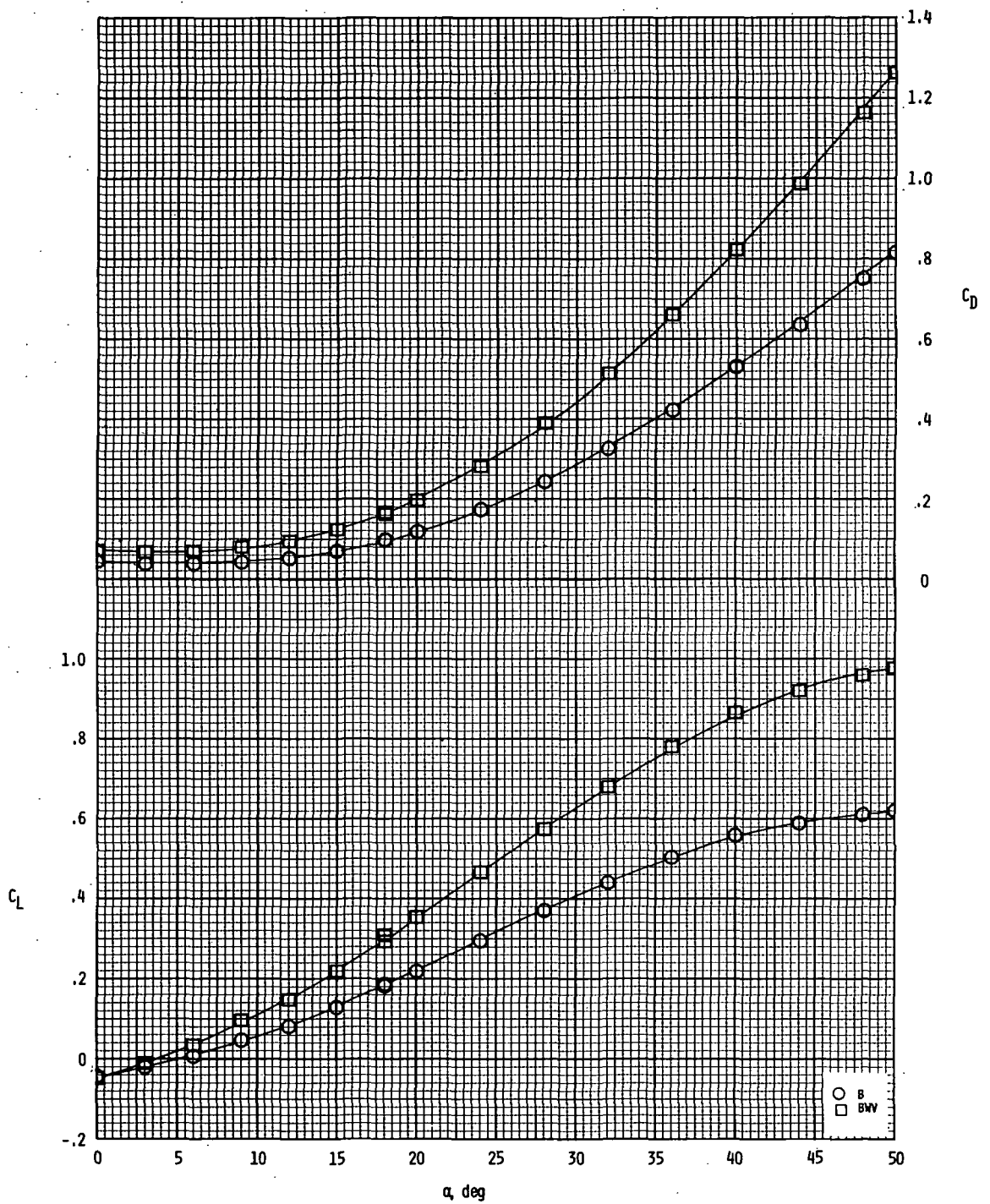
(a) C_A and C_N plotted against α .

Figure 6.- Effect of component buildup on longitudinal characteristics over complete angle-of-attack range. Model 2; $M = 20.3$; $R_1 = 3.27 \times 10^6$.



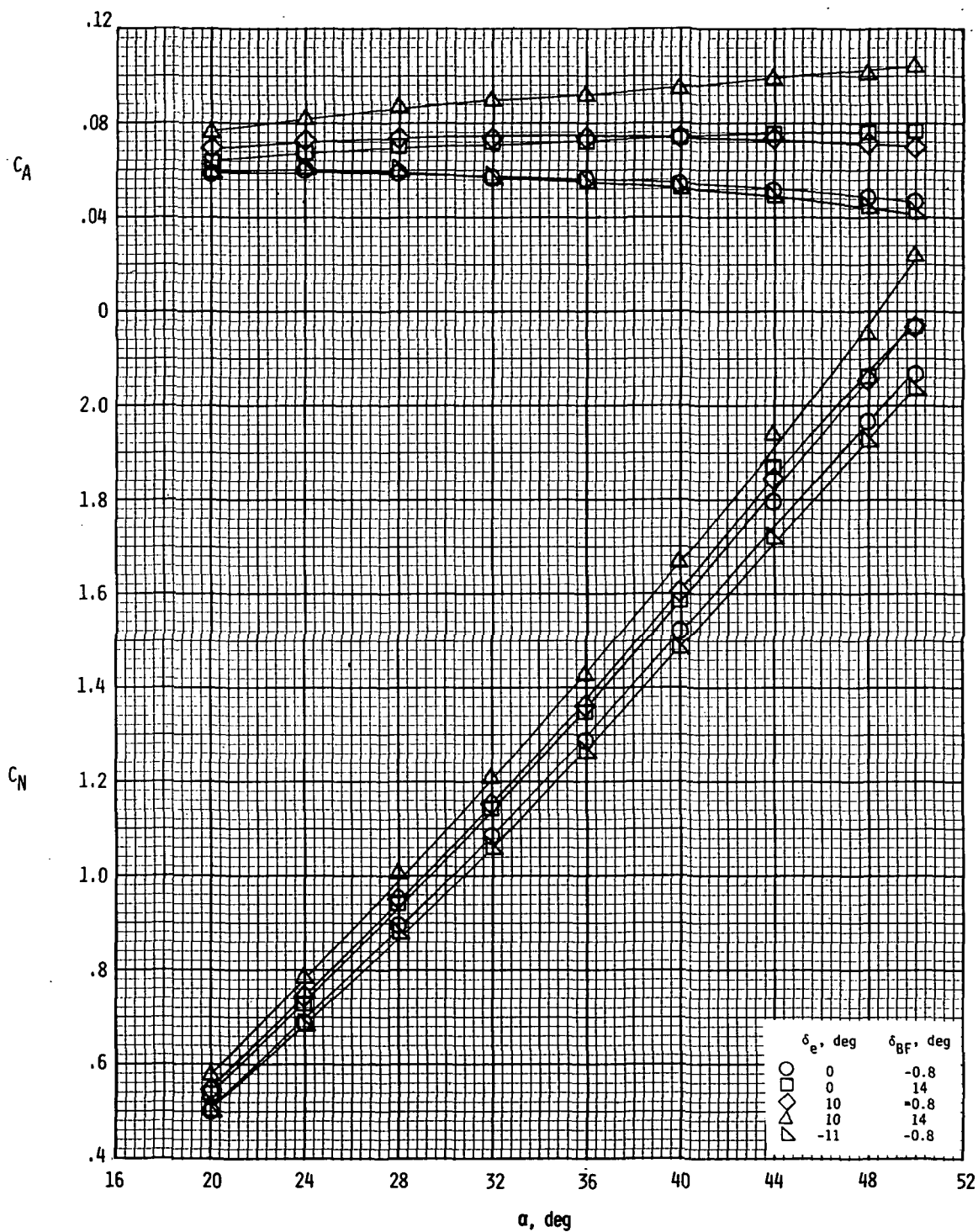
(b) L/D and C_m plotted against α .

Figure 6.- Continued.



(c) C_D and C_L plotted against α .

Figure 6.- Concluded.



(a) C_A and C_N plotted against α .

Figure 7.- Effect of control deflections on longitudinal characteristics at high angles of attack. Model 1; $M = 20.3$; $R_1 = 3.79 \times 10^6$.

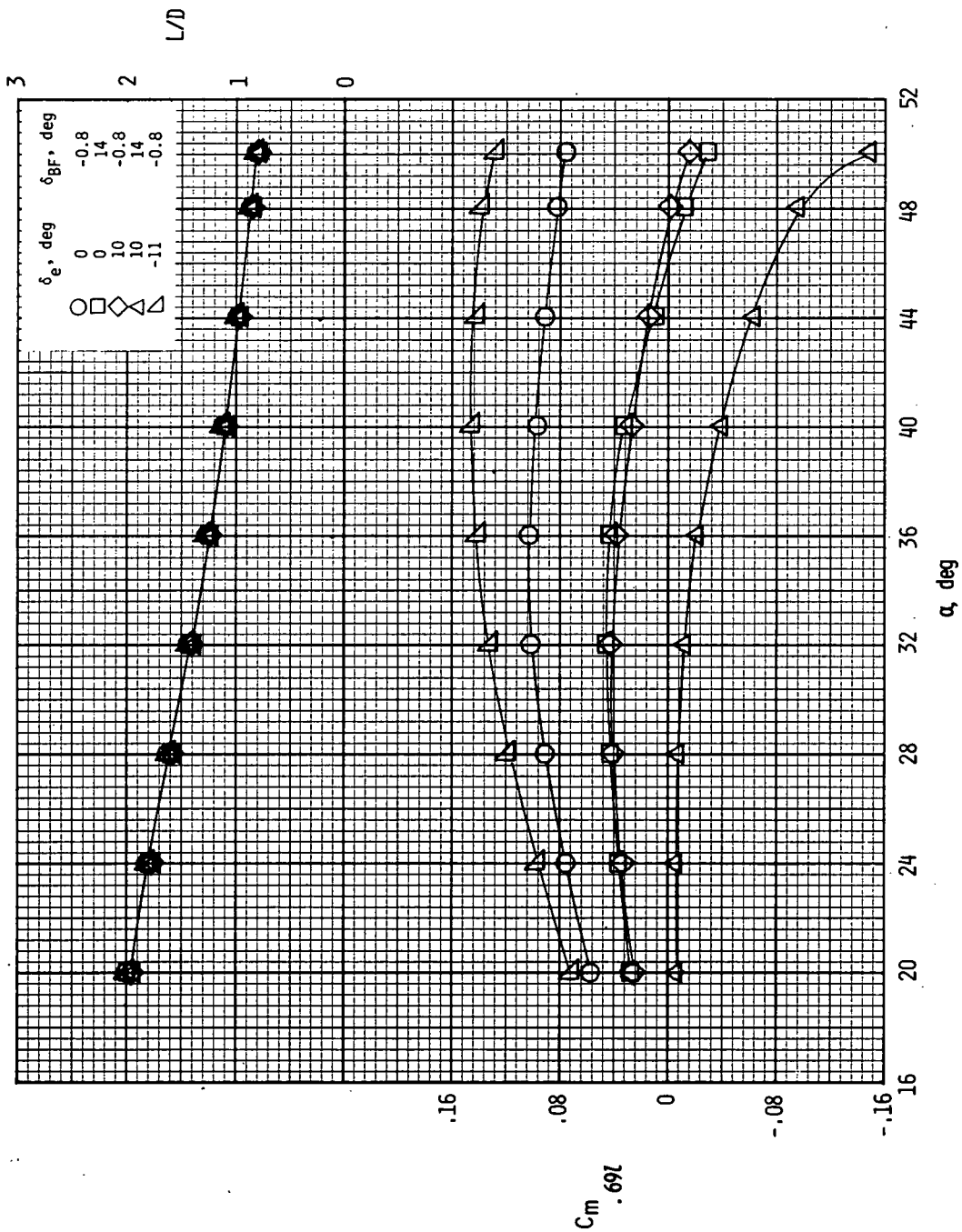
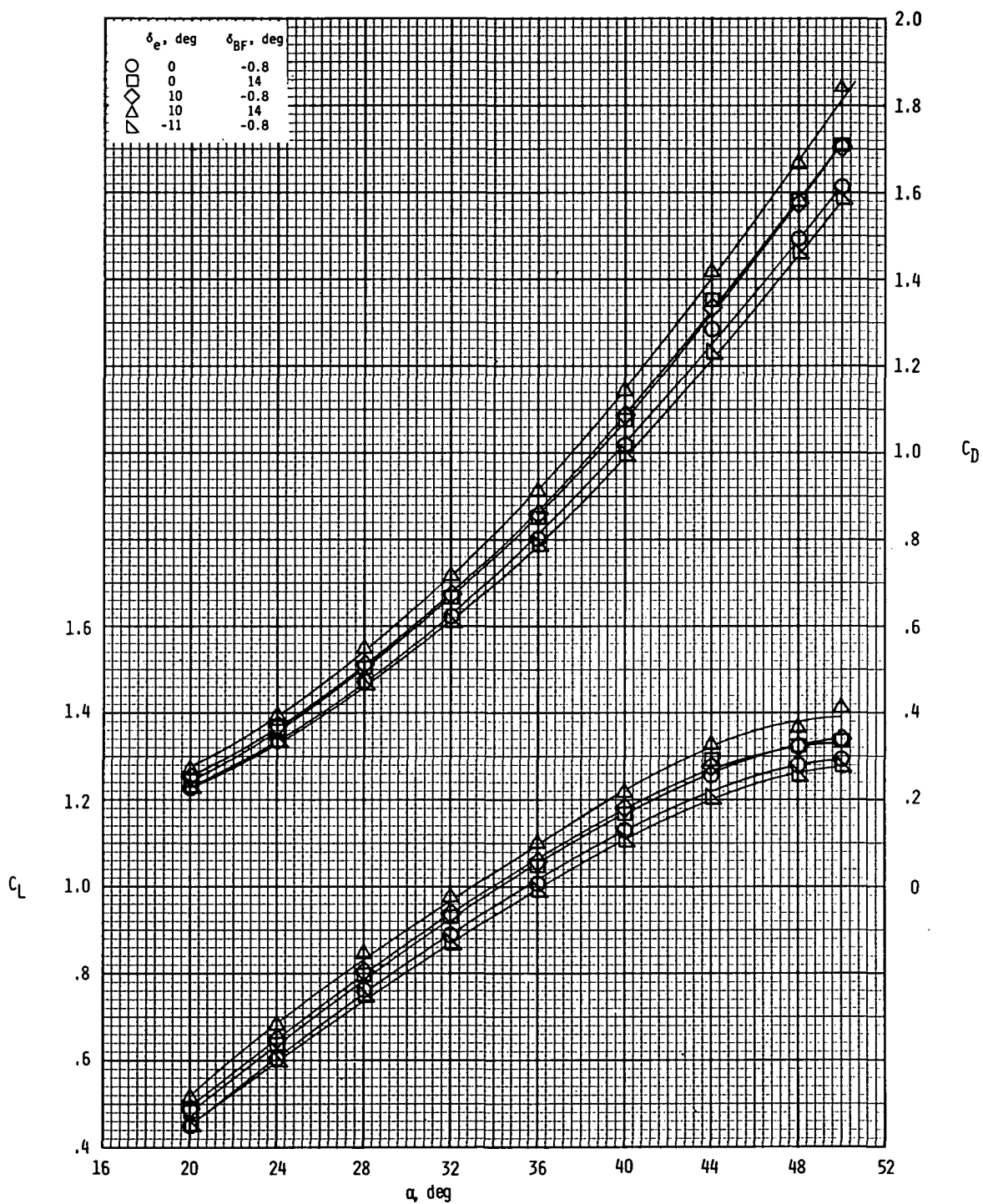
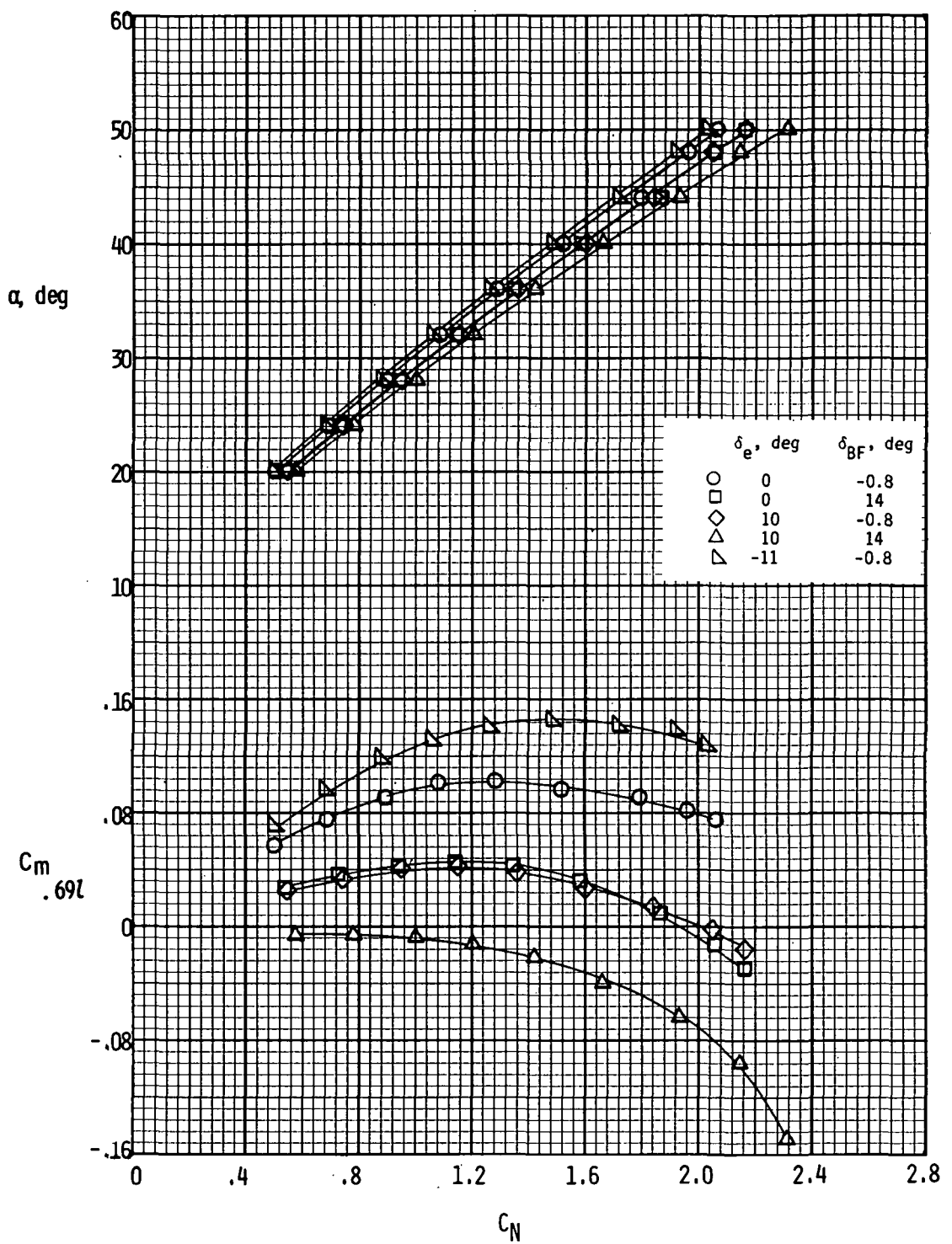
(b) L/D and C_m plotted against α .

Figure 7.- Continued.



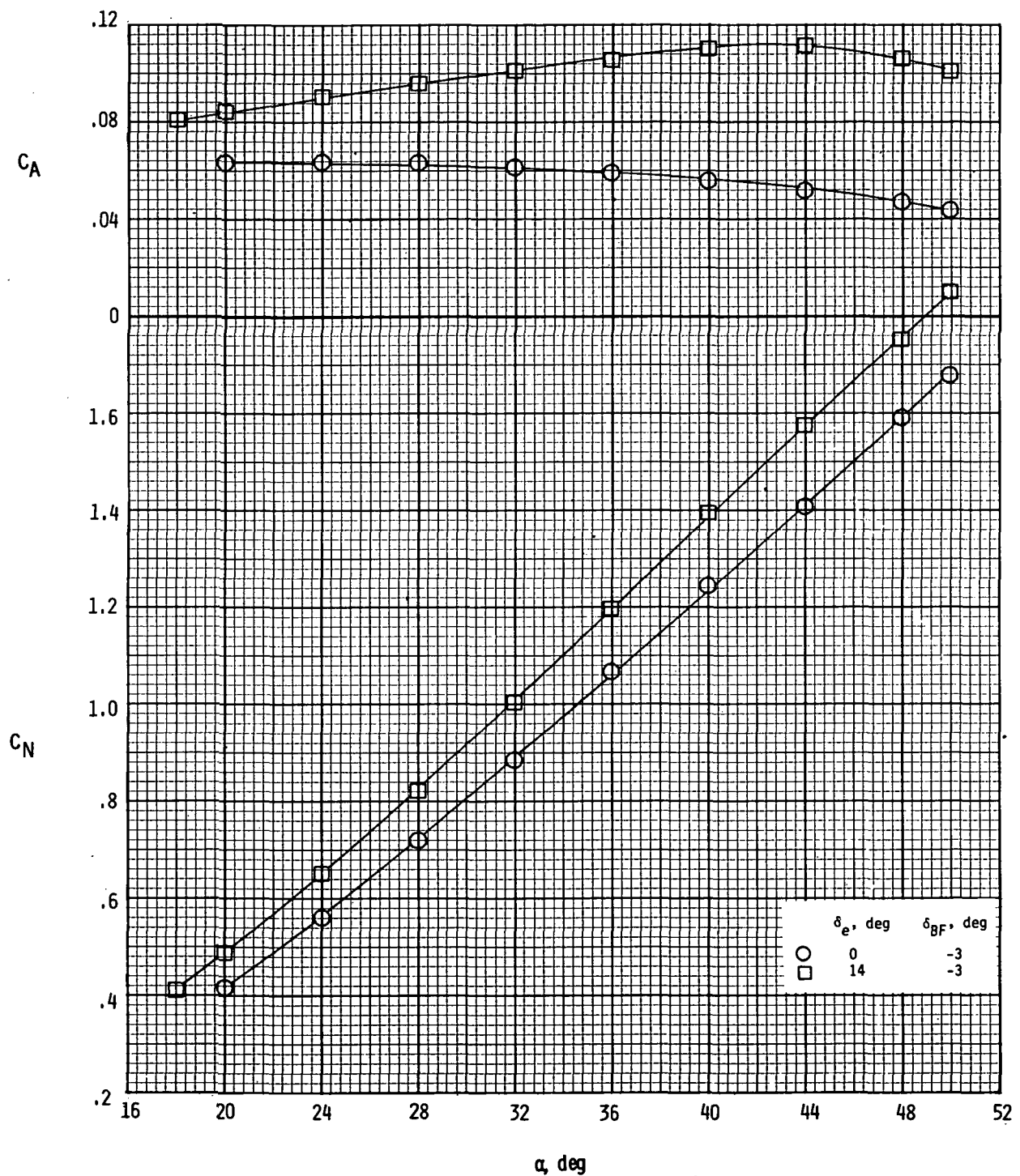
(c) C_D and C_L plotted against α .

Figure 7.- Continued.



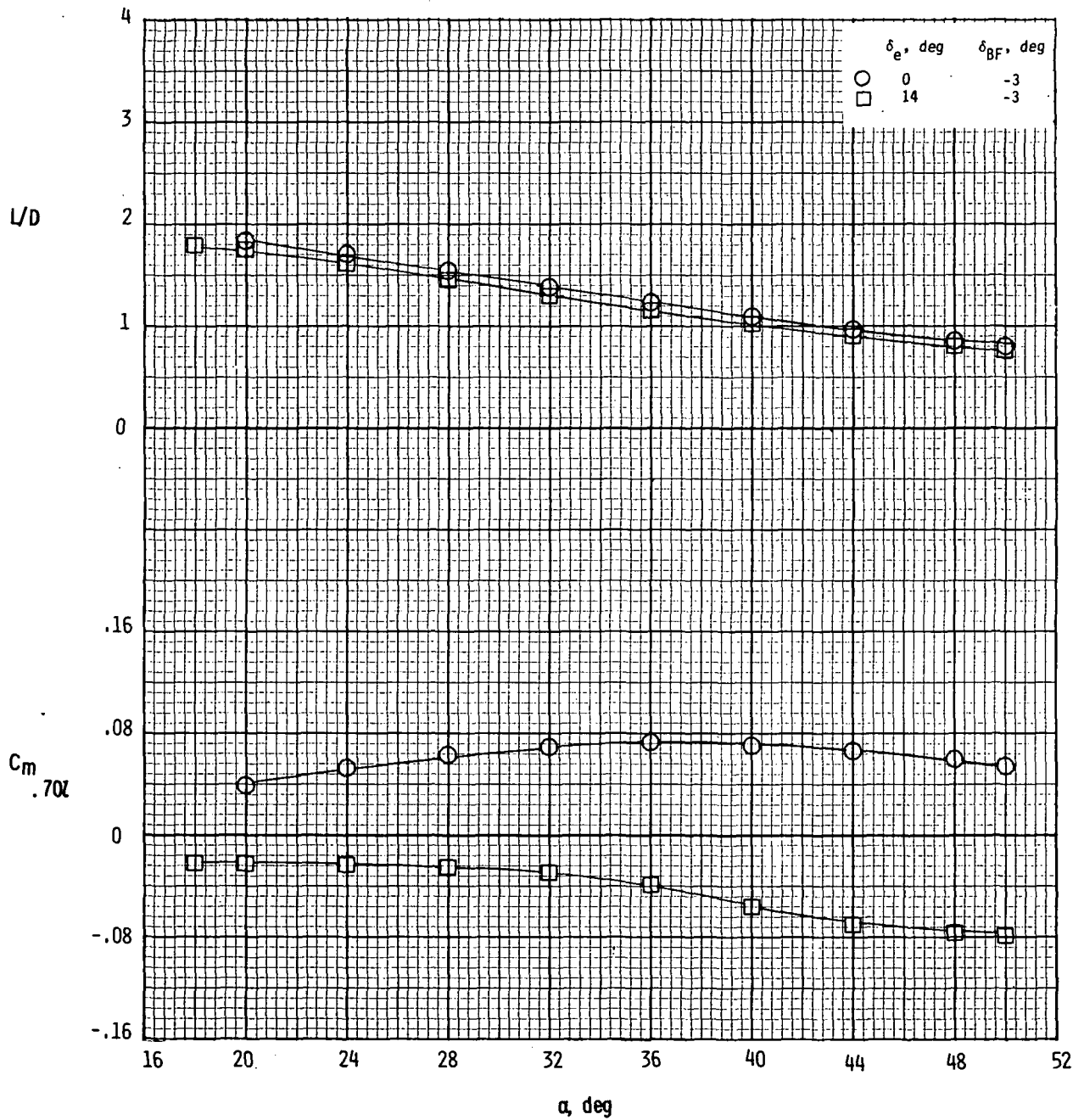
(d) α and C_m plotted against C_N .

Figure 7.- Concluded.



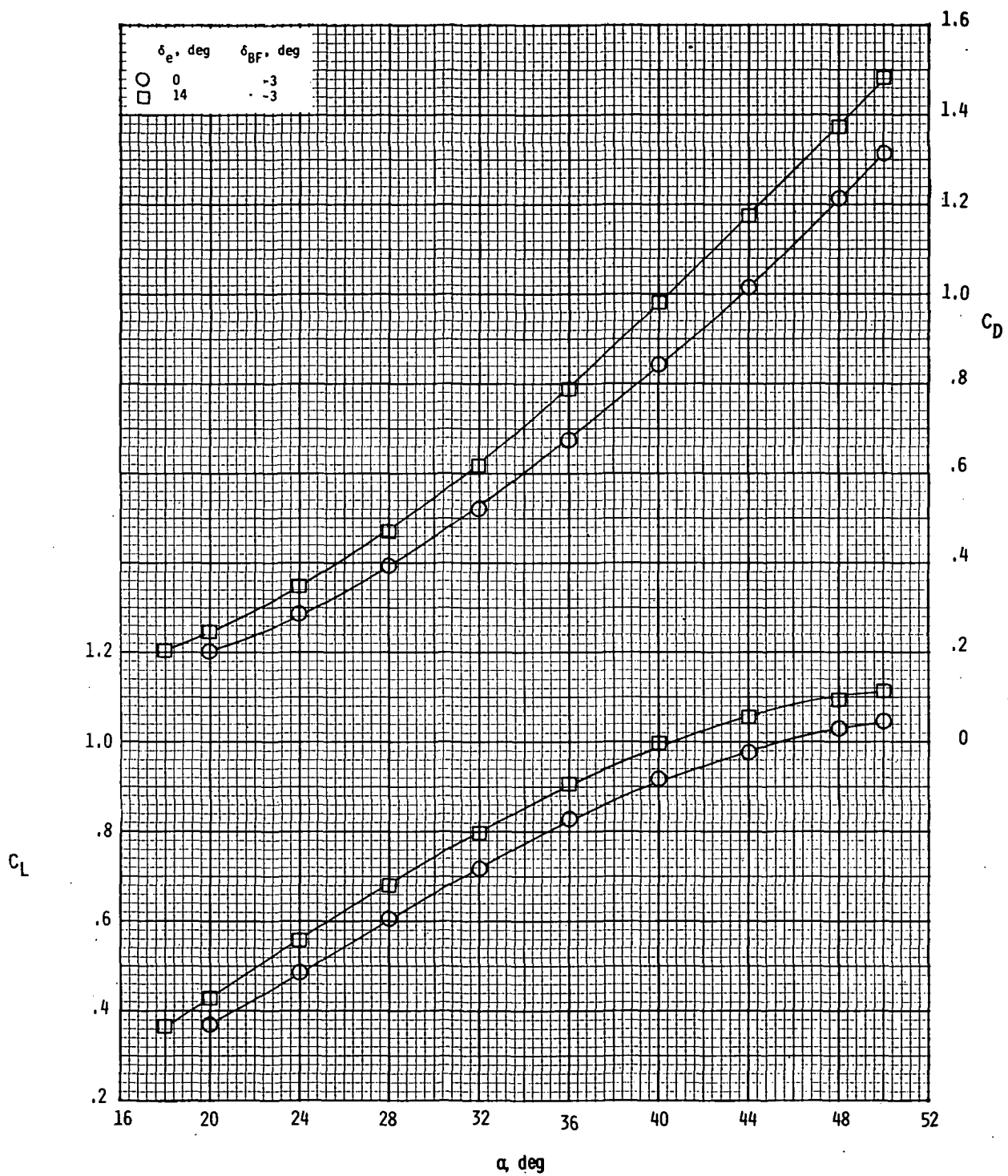
(a) C_A and C_N plotted against α .

Figure 8.- Effect of control deflections on longitudinal characteristics at high angles of attack. Model 2; $M = 20.3$; $R_1 = 3.27 \times 10^6$.



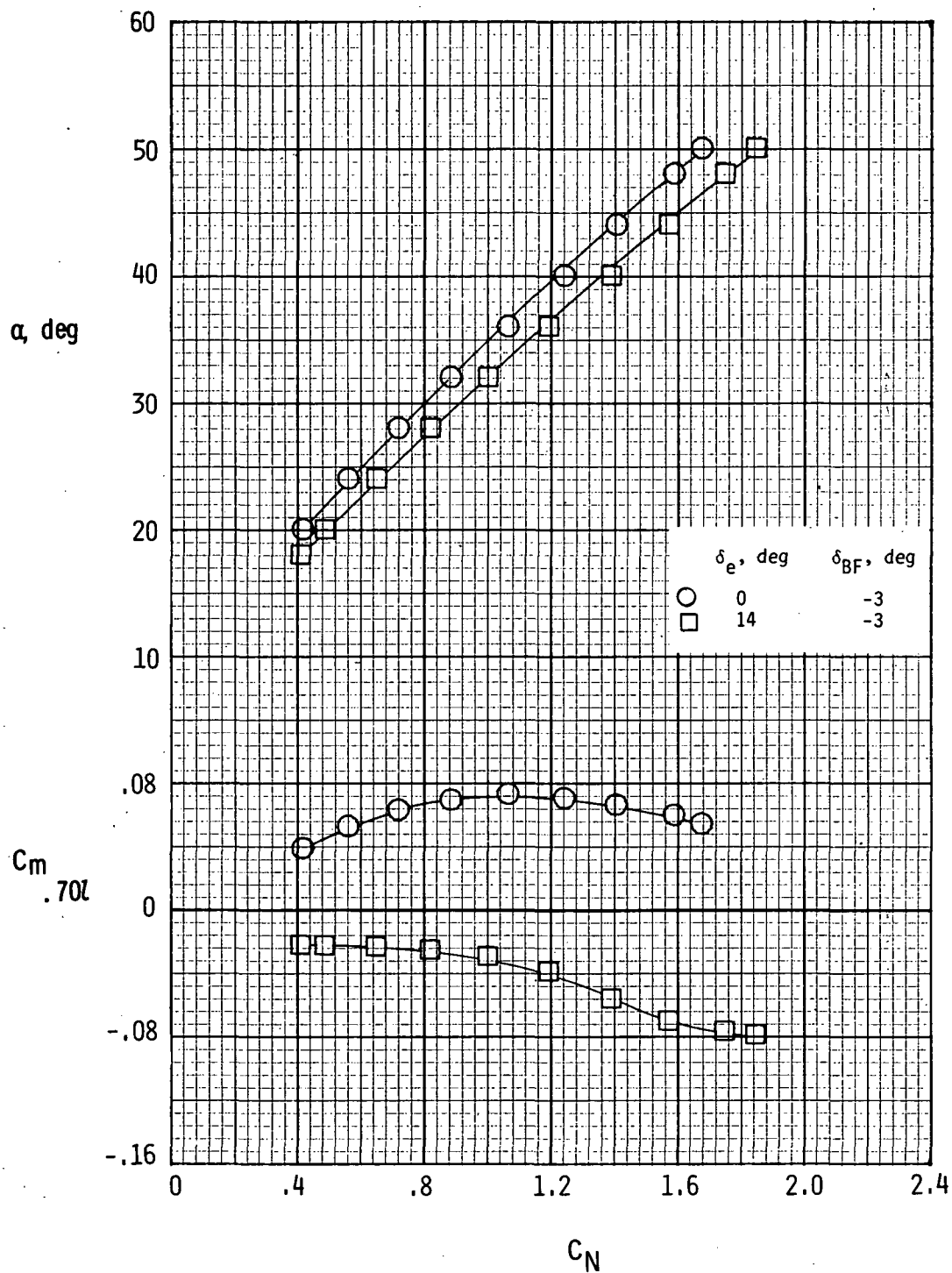
(b) L/D and C_m plotted against α .

Figure 8.- Continued.



(c) C_D and C_L plotted against α .

Figure 8.- Continued.



(d) α and C_m plotted against C_N .

Figure 8.- Concluded.



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